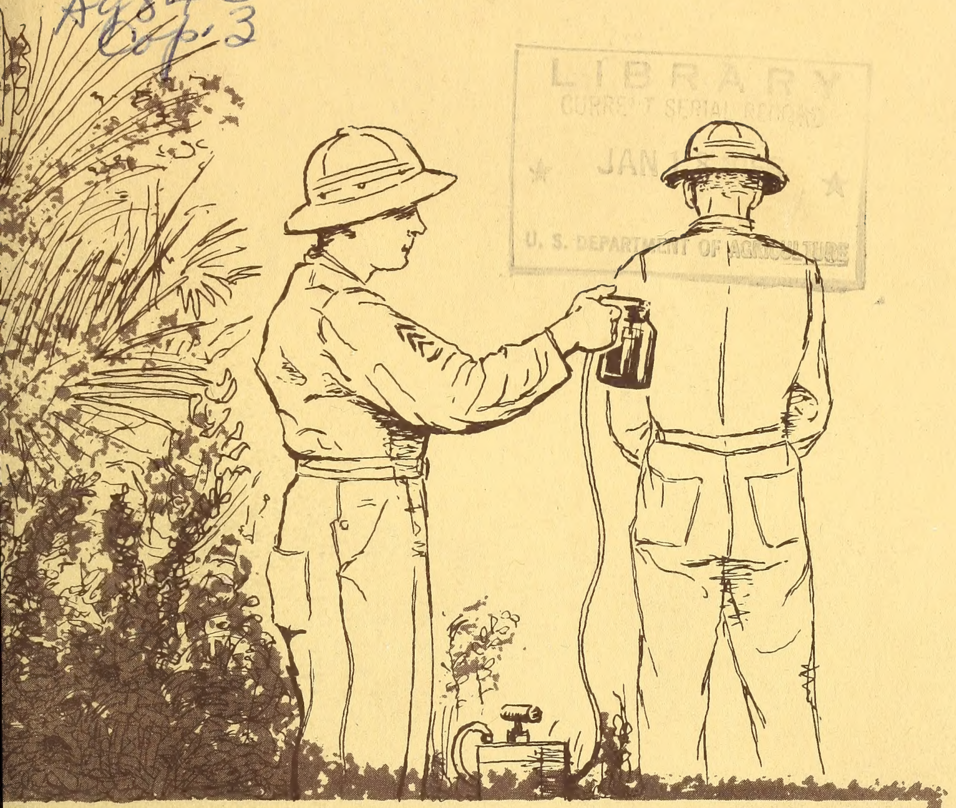

INSECTICIDES and REPELLENTS for the control of insects of medical importance to the ARMED FORCES

CIRCULAR No. 977
UNITED STATES DEPARTMENT OF AGRICULTURE

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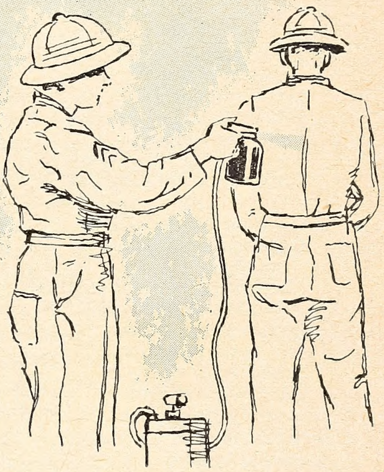

PREPARED by the Orlando, Fla., Laboratory of the Entomology Research Branch, Agricultural Research Service

CIRCULAR NO. 977 DECEMBER 1955

U. S. DEPARTMENT OF AGRICULTURE • WASHINGTON, D. C.

CONTENTS

This circular supersedes Miscellaneous Publication 606, DDT and Other Insecticides and Repellents Developed for the Armed Forces.

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INSECTICIDES and REPELLENTS for the control of insects of medical importance to the ARMED FORCES[1]

Prepared by the Orlando, Fla., Laboratory of the Entomology Research Branch, Agricultural Research Service

INTRODUCTION

SOON after the outbreak of World War II the need for improved methods for controlling the insect vectors of various diseases of importance to military personnel engaged in a worldwide conflict was recognized by medical officers in the office of the Surgeon General, U. S. Army, and by civilian consultants on military medical problems. Research to develop such measures was undertaken by the former Bureau of Entomology and Plant Quarantine in 1942 at the request of the War Department. Most of this research has been conducted at Orlando, Fla., but some studies have been made at Beltsville, Md., and Savannah, Ga.

This research was financed by the Office of Scientific Research and Development on recommendation of the Committee on Medical Research of the National Research Council until the end of the war in 1945. Financial support was then provided by the War Department and since has been assumed by the Departments of the Army and Navy. These programs have been reviewed and sponsored by the Army Committee for Insect and Rodent Control.

The following branches of the Department of Defense have assisted in conducting the work and in furnishing personnel, supplies, and equipment: The offices of the Quartermaster General, the Chief of Engineers, and Chief Chemical Officer of the Department of the Army; the U. S. Army Typhus Commission; the Army Air Forces Center, Orlando, Fla.; Brooke Army Medical Center; and other Army posts. Informal cooperation was also received from the Food and Drug Administration, the National Institutes of Health, the Army Environmental Health Laboratory, the Tennessee Valley Authority, the Rockefeller Foundation, and the Arkansas State Board of Health.

In the course of this work thousands of new chemicals and chemical formulations have been investigated as insecticides and repellents. Much of the information obtained has been reported in scientific publications dealing with specific subjects. Those materials and methods that have proved to be or offer promise of being of practical value are summarized in this circular. Information available at the end of the war was reported in Miscellaneous Publication No. 606, entitled "DDT and Other Insecticides and Repellents Developed for

[1] Submitted for publication May 17, 1955.

the Armed Forces." This circular includes much new information obtained since that publication was issued.

Although the work has been carried out principally to develop control measures applicable under military conditions, most of the methods developed are also applicable with modifications to civilian problems.

It has been impossible to investigate all materials against all major insects. The most emphasis has been given to mosquitoes because of their importance as disease transmitters and as serious pests. Extensive research has also been conducted on the control of flies, lice, chiggers, ticks, fleas, and sand flies, and some study has been given to bed bugs and cockroaches. The insects mentioned in this circular are given below.

Body louse	*Pediculus humanus humanus* L.
Head louse	*Pediculus humanus capitis* Deg.
Crab louse	*Phthirus pubis* (L.).
Common malaria mosquito	*Anopheles quadrimaculatus* Say.
Yellow-fever mosquito	*Aedes aegypti* (L.).
Southern house mosquito	*Culex quinquefasciatus* Say.
Salt-marsh mosquitoes	*Aedes sollicitans* (Wlkr.) and *taeniorhynchus* (Wied.).
Southern buffalo gnat	*Cnephia pecuarum* (Riley).
House fly	*Musca domestica* L.
Stable fly	*Stomoxys calcitrans* (L.).
Human flea	*Pulex irritans* L.
Oriental rat flea	*Xenopsylla cheopis* (Rothsch.).
Cat flea	*Ctenocephalides felis* (Bouché).
Dog flea	*Ctenocephalides canis* (Curt.).
Bed bugs	*Cimex lectularius* L. and *hemipterus* (F.).
Imported fire ant	*Solenopsis saevissima* v. *richteri* Forel.
Chiggers	*Trombicula splendens* Ewing and *alfreddugèsi* (Oud.).
Itch mite	*Sarcoptes scabiei* (Deg.).
American dog tick	*Dermacentor variabilis* (Say).
Lone star tick	*Amblyomma americanum* (L.).
Brown dog tick	*Rhipicephalus sanguineus* (Latr.).

Most of the species have served as test insects at Orlando. Although they are predominantly American species, it is believed that control measures developed against them will aid in the control of related species throughout the world. Since related species may vary considerably in habits and susceptibility to chemicals, and since the conditions under which chemicals and equipment are used may influence their effectiveness, the suggestions and procedures in this circular should be considered only as a guide and subject to adaptations.

Although recommendations have been based chiefly on the investigations conducted by the former Bureau of Entomology and Plant Quarantine, other available information has also been taken into account. Much information on the control of insects in various parts of the world has been obtained by military personnel during and since World War II. Many agencies in the United States and in other countries have undertaken large-scale control programs.

CHEMISTRY OF INSECTICIDES AND REPELLENTS

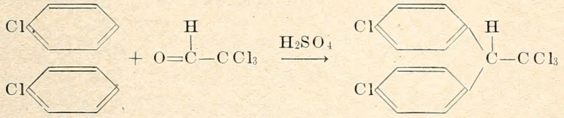
DDT

History and Preparation

DDT was first synthesized in Germany in 1874, but it was not until 1939 that the Swiss firm of J. R. Geigy, S. A., reported the compound to be effective as an insecticide against clothes moths, flies in stables, and certain agricultural insect pests.

Samples for the initial research were furnished by the Geigy Co., Inc., New York City, a subsidiary of J. R. Geigy, S. A. The first samples were received at Orlando in October 1942.

The chemical name of DDT is 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane. The term "DDT" is derived from the generic name dichloro-diphenyl-trichloroethane. The compound is prepared from 2 molecules of monochlorobenzene and 1 molecule of chloral or chloral hydrate in the presence of a suitable condensing agent, such as sulfuric acid. The equation is as follows:



Monochlorobenzene Chloral *p,p'*-DDT

The chlorine atoms may occur in different positions on the benzene ring to form different isomers. The DDT crystallizes from the reaction mass, and the sulfuric acid is removed by washing. The technical product contains from 70 to 77 percent of the *p,p'* isomer and from 15 to 25 percent of the *o,p'* isomer, which is much less toxic. Pure *p,p'*-DDT may be obtained by several recrystallizations of the technical material from ethyl alcohol.

Properties

Pure *p,p'*–DDT is a white crystalline substance melting at 108.5°–109° C. The technical product melts at a lower temperature, and the Federal specification calls for a minimum setting point of 89°. The aerosol grade has a melting point of not less than 103°. The specific gravity of the compound is about 1.6. It is stable under ordinary conditions.

DDT is nearly insoluble in water, but is moderately soluble in petroleum and vegetable oils, and readily soluble in many other organic solvents. Table 1 shows the approximate solubilities at 27°–30° C. (81°–86° F.) for once-recrystallized DDT (m. p. 107.5°–108° C.) or technical DDT in some of the common solvents.

TABLE 1.—*Characteristics of various solvents for DDT*[1]

Solvent	Density	Boiling point	Flash point [2]	Solubility of DDT
ORGANIC COMPOUNDS	*Grams per milliliter*	° *F.*	° *F.*	*Grams per 100 ml. of solvent*
Acetone	0.79	133	14	58
Benzene	.88	176	<20	78
Benzyl benzoate	1.11	433		42
Carbon tetrachloride	1.60	169	(3)	45
Cyclohexanone	.95	315	122	116
o-Dichlorobenzene	1.30	356	167	59
Dimethyl phthalate	1.19	360	300	34
Ethyl alcohol, 95 percent	.81	172	167	2
Ethylene dichloride	1.26	183	70	59
Isophorone	.92	419	205	74
Tetrachloroethylene	1.63	250		38
Tetrahydronaphthalene	.97	405	180	61
Trichloroethylene	1.47	190	(3)	64
Xylene (10-degree)	.86	275–293	80–85	53
o-Xylene	.87	291		57
Petroleum oils:				
Fuel oil:				
No. 1	.82–.84			8–11
No. 2	.84–.86			7–10
Gasoline	.72–.75	140–248		10
Kerosene, regular run, crude	.80–.82	345–525	150	8–10
Kerosene, refined, odorless	.81 (max.)	177–277	125 (min.)	4
Stoddard solvent		350–410	>100	9
OTHER HYDROCARBON SOLVENTS [4]				
Amsco Solv H-La			220	30
Bronoco Hi-Sol:				
No. 4	.93–1.00	410–580	>175	32
No. 100	.99–1.00	420–750	[5] >250	35
Hi-Flash Solvent	.88	302–392	114	48
Hi-Solv Oil No. 473			186	30
Saf-T-Sol No. 1	.92	364–663	165	30
Solvesso No. 3	.88	343–410	155	33
S/V Sovacide:				
544–B	.99	525–640	275	45
544–C	.95	475–570	245	38
544–F	.93	474–740	250	27
Umex. 4060	.93	420–546	210	27
Velsicol:				
AR–40	.93–.95	390–485	180	59
AR–50	.97	457–516	230	55
AR–50	.96–.98	390–550	180	65
AR–50G	.95–.96	390–550	180	44
AR–60	.98–1.00	460–560	220	55
NR–70	1.04	496–675	300	52
NR–70	.97–1.00	420–680	200	53

[1] Mention of proprietary products in this table and throughout this circular does not constitute their endorsement by the U. S. Department of Agriculture.
[2] Cleveland open cup (COC).
[3] Nonflammable.
[4] Most of the data on these solvents were furnished by the producers; grade of DDT was not specified.
[5] Tag closed cup.

Methods of Analysis

The setting point of not less than 89° C. is a simple and effective check on the quality of technical DDT and is used in specifications as a criterion of its purity. It is determined from the cooling curve of a molten sample under specified conditions.

DDT is determined quantitatively by the total organically bound chlorine method (A. O. A. C. *1*),[2] in which the sample is refluxed with metallic sodium in isopropanol. The resulting inorganic chlorides may be determined by any of the recognized procedures—Volhard and its modifications, electrometric, or amperometric. Total chlorine may also be determined by a Carius combustion, with subsequent analysis for the inorganic chloride. The factor for total chlorine to DDT is 2. The total-chlorine determination is not specific for DDT; so it is of value only when it is known that DDT is the only chlorine compound present.

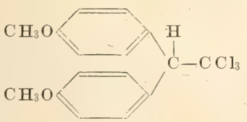
Another method, but also not specific for DDT, is known as the labile, or hydrolyzable, chlorine method (Wichmann *et al. 15*). The sample is refluxed with alcoholic alkali with the result that hydrogen chloride is eliminated and the chloride may be determined as inorganic chloride. The DDT may be calculated from the labile chlorine by use of the factor 9.9441.

The *p,p'*-isomer content of technical DDT may be ascertained by a crystallization method described by Cristol *et al.* (*3*). Ethanol (75 percent in water) is saturated with *p,p'*-DDT at 25° C. The technical DDT is added and dissolved by refluxing. When cooled to 25° C., the *p,p'* isomer of the added DDT will crystallize and may be weighed.

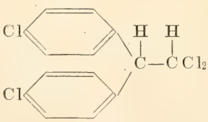
A colorimetric method (A. O. A. C. *1*) for small quantities is based on the formation of a tetranitro derivative that reacts with sodium methoxide to give a blue color for the *p,p'* isomer and a reddish purple for the *o,p'* isomer. This method is primarily for spray-residue and other analyses where small quantities of DDT are present, but it has application also in technical and formulation analyses. It is rather specific, but certain other insecticides, such as methoxychlor, Dilan, and TDE, interfere.

METHOXYCHLOR AND TDE

A large number of DDT analogs have been synthesized, and some have shown a high degree of toxicity to insects. Two that are commercially available and are employed in the control of insects affecting man are methoxychlor (1,1,1-trichloro-2,2-bis(*p*-methoxyphenyl)ethane) and TDE (1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane).



Methoxychlor



TDE

[2] Italic numbers in parentheses refer to Literature Cited, p. 91.

Methoxychlor is effective in space sprays and residual treatments against house flies. It is less toxic than DDT to warm-blooded animals, and is not stored in animal fat to the same extent. TDE has given good results as a mosquito larvicide. It is slightly less toxic than DDT to the larvae but is also less toxic to fish and mammals. Neither of these insecticides is available as a military-issue item.

BENZENE HEXACHLORIDE

Properties

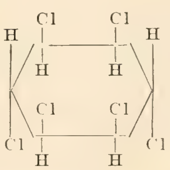
Benzene hexachloride (BHC) was first prepared by Michael Faraday in 1825. Its insecticidal properties apparently were first investigated in France in 1940 and in England in 1942. A French patent was issued to A. Dupire in 1941. This chemical was designated in England as 666 from its molecular formula $C_6H_6Cl_6$. The chemical name is 1,2,3,4,5,6-hexachlorocyclohexane. It is prepared by the chlorination of benzene in the presence of ultraviolet light.

The crude material contains five known stereoisomers. The gamma isomer, which is the most toxic to insects, constitutes only about 12 percent of the product and the alpha isomer 60 to 70 percent. Partly refined products containing from 36 to 90 percent of the gamma isomer are available, and also a refined product consisting of nearly pure gamma.

Gammexane is a proprietary name that originated in England and has appeared in European literature for the gamma isomer. Lindane is the common name that has been approved by the U. S. Interdepartmental Committee on Pest Control for a product containing not less than 99 percent of the gamma isomer. It is considerably more expensive to produce than the partly refined material but is coming into extensive use because of its high toxicity to many economic species.

The crude and partly refined materials have a pronounced musty odor. In the pure gamma isomer, however, the odor is much reduced, and the product is employed in household sprays in many countries, including the United States.

Gamma benzene hexachloride is a white crystalline material, is very stable to oxidation, and has a melting point of 112.5° C. It has the following structural formula:



It is nearly insoluble in water and is less soluble than DDT in most petroleum oils and other solvents. Its solubilities in some common solvents are as follows:

Solvent	Grams per 100 grams of solution
Data by Slade (*13*):	*At 20° C.*
Acetone	43.5
Benzene	28.9
Carbon tetrachloride	6.7
Cyclohexanone	36.7
Diesel oil	4.1
Ethyl alcohol	6.4
Ethylene dichloride	38.9
Odorless distillate (b. p. 198°–257° C.)	2.0
Paraffin (kerosene) (b. p. 138°–212° C.)	3.2
Tetrachloroethylene	7.4
Toluene	27.6
Xylene	24.7
Data by the Velsicol Corporation for lindane:	*At 25° C.*
AR–50	21.3
AR–50G	18.4
AR–60	21.0

Considerable work has been done at the Orlando laboratory on the selection of solvents for emulsifiable concentrates. Of the materials having a minimum flash point of 135° F., isophorone was the only one that would dissolve and hold more than 20 percent of lindane at low temperatures (25–29 percent at 0°). The solvents that were satisfactory for 20-percent solutions at room temperatures (80°–85°) but not at 23° were Solvesso No. 150; Velsicol AR–50, AR–50G, and AR–60; and S/V Sovacide 544–B, 544–C, and 544–F. At 0° lindane was soluble up to 10 percent in S/V Sovacide 544–B and Velsicol AR–50 and AR–60.

In tests with BHC containing 39 percent of gamma, Velsicol AR–60 dissolved 25 percent, isophorone 50 percent, and an 85:15 mixture of the two 40 percent at room temperature. In further tests with this material and lindane in mixtures of fuel oil and S/V Sovacide 544–C at room temperatures the following approximate solubility data were obtained:

Percent of S/V Sovacide 544–C in fuel oil	*Grams per 100 ml. of solution* — *Lindane*	*BHC (39% gamma)*
0	2.5	7.2
10	4.5	9.7
15	5.0	10.0
20	5.5	10.2
25	5.7	11.2
30	6.2	11.5

For aerial applications for the control of mosquitoes, xylene was also a satisfactory auxiliary solvent. It was either mixed with the fuel oil or used to prepare a 20- to 25-percent concentrate for dilution with fuel oil.

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Methods of Analysis

The total-chlorine determination as described for DDT (p. 5) may also be used for the assay of benzene hexachloride, although it is of value only when it is known that this is the only chlorine compound present. The total-chlorine determination does not give any indication as to the gamma-isomer content. However, it may be used for the determination of lindane under the same conditions as for BHC—i. e., it is not specific. The factor for total BHC and for lindane from the total-chlorine content is 1.3665.

The labile, or hydrolyzable, chlorine determination as reported for DDT (p. 5) may also be used for BHC and lindane, although again the method is not specific. The factor for calculating BHC and lindane is 2.7330.

An infrared spectrometric method (Daasch *4*) may be used to determine the gamma-isomer content, as well as that of the other isomers in technical BHC in the absence of more than very small quantities of other chlorinated cyclohexanes.

The gamma-isomer content of technical BHC and of formulations containing it is determined by the partition-chromatographic method (Harris *7*), in which this isomer is separated from the other components by passing a hexane-nitromethane solution of the sample through a silicic acid column. The BHC isomers are eluted with the hexane-nitromethane solution. The solvent is removed by evaporation from that portion of the eluate containing the gamma isomer, and the gamma isomer is weighed.

The gamma isomer may also be determined by polarography (Dragt *6*). This is the only isomer that is reduced at the dropping-mercury electrode under the conditions stipulated in the methods used.

A simple cryoscopic method (Toops and Riddick *14*) for determining the gamma-isomer content of BHC has been refined, and since it has an accuracy of ± 0.05 percent it is of value for the characterization and determination of lindane.

A sensitive colorimetric method (Schechter and Hornstein *12*) for determining small quantities of BHC has been devised. It is based on the dechlorination of this compound to benzene by means of zinc and acetic acid with subsequent nitration of the benzene and reaction with 2-butanone in the presence of strong alkali to give a violet-red color that may be measured photometrically. The method is not specific for lindane.

CHLORDANE AND HEPTACHLOR

Properties

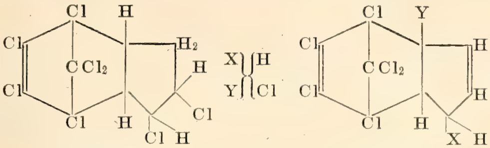
The effectiveness of chlordane as an insecticide was announced by Kearns and associates (*10*) in 1945. It was referred to as 1068 from its molecular formula $C_{10}H_6Cl_8$. It has also been called Octa-Klor. Its chemical name is 1,2,4,5,6,7,8,8-octachloro-2,3,3*a*,4,7,7*a*-hexahydro-4,7-methanoindene. Technical chlordane contains 60 to 70 percent of chlordane and 25 to 40 percent of related compounds occurring in the normal manufacturing processes.

Chlordane is a viscous amber liquid, with a boiling point of 175° C. at 2-mm. pressure. The technical product has a specific gravity of

1.57–1.67, is nearly insoluble in water, but is miscible or soluble in all proportions in nearly all organic solvents and petroleum oils, including refined kerosene.

A closely related compound, heptachlor, was first isolated by a process of chromatographic adsorption from technical chlordane. It has a melting point of 92°–93° C., its molecular formula is $C_{10}H_5Cl_7$, and its chemical name is 1 (or 3*a*),4,5,6,7,8,8-heptachloro-3*a*,4,7,7*a*-tetrahydro-4, 7-methanoindene. It, too, is highly active insecticidally.

The structural formulas of the two compounds are shown below.



Chlordane Heptachlor

Methods of Analysis

The total-chlorine determination as used for DDT and benzene hexachloride (see pp. 5 and 8) may also be used for chlordane and heptachlor when present singly, although it must be kept in mind that this is not a specific method.

Chlordane reacts with diethanolamine in the presence of methanolic potassium hydroxide, yielding a mixture of colored compounds. The intensity of the overlapping colors may be determined at 550 millimicrons on a Beckman DU spectrophotometer. Heptachlor may interfere with the determination of chlordane in this method.

The reaction between heptachlor and potassium hydroxide, monoethanolamine, and Butyl Cellosolve produces a pink to intense violet complex that is specific for heptachlor in the presence of chlorinated hydrocarbons other than technical chlordane. The intensity of color is suitable for use in analysis.

DIELDRIN AND ALDRIN

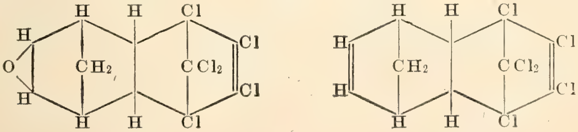
Properties

Dieldrin and aldrin were developed in 1948. They are whitish crystalline solids and are highly active insecticidally. Dieldrin, which is an oxygenated derivative of aldrin, is the more toxic to most insects, and its insecticidal action is more persistent. It has been superior to aldrin for controlling many of the insects affecting man. The chemical names, molecular formulas, and melting points of the pure compounds are as follows:

Dieldrin. 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4*a*,5,6,7,8,8*a*-octahydro-1,4,5,8-dimethanonaphthalene; $C_{12}H_8Cl_6O$; m. p. 172°–175° C.

Aldrin. 1,2,3,4,10,10-hexachloro-1,4,4*a*,5,8,8*a*-hexahydro-1,4,5,8-dimethanonaphthalene; $C_{12}H_8Cl_6$; m. p. 100°–103° C.

The structural formulas are shown below.



Dieldrin Aldrin

Technical dieldrin contains not less than 85 percent and technical aldrin not less than 95 percent of the pure compound. Recrystallized products contain not less than 99 percent of the pure compounds. Aldrin is also commonly sold as an oily solution designated as "60 percent aldrin equivalent solution," which contains 57 percent of the pure compound and 43 percent of chlorinated and hydrocarbon solvents normally resulting from the manufacturing process. For formulation purposes 1⅔ pounds of this solution is considered to be equivalent to 1 pound of aldrin. It has a tan color and a specific gravity of 1.33–1.48. It is miscible in all proportions in the common hydrocarbon solvents.

The approximate solubilities in representative solvents are shown below.[3]

Solvent	Grams per 100 ml. of solvent at 25° C. — Dieldrin	Grams per 100 ml. of solvent at 25° C. — Aldrin
Acetone	26	109
Benzene	56	183
Carbon tetrachloride	48	303
Deobase	4	18
Ethylene dichloride	70	312
Kerosene, deodorized	5	28
Shell E–407R	26	-------
Summer diesel (fuel oil)	17	30
S/V Sovacide 544–C	37	-------
Toluene	54	267
Xylene	52	235

Methods of Analysis

The methods for the determination of total organically bound chlorine as used for DDT may also be used for dieldrin and aldrin when it is known that other organic chlorine compounds are absent. The factors for converting organically bound chlorine to aldrin and dieldrin are 1.715 and 1.789, respectively. The method is not specific.

Both dieldrin and aldrin may be determined by infrared spectroscopy. The 8.48-micron absorption peak for aldrin and the 10.98- and 11.808-micron absorption peaks for dieldrin have been recommended. Aldrin and dieldrin would interfere with each other if present in the same sample.

A colorimetric method for aldrin is based on its reaction with phenyl azide to yield a triazole derivative that couples with diazotized 2,4-dinitroaniline in the presence of concentrated hydrochloric acid to give a red color, the intensity of which may be read on a spectrophotometer at 515 millimicrons. Other common insecticides do not interfere.

Dieldrin may be determined by reacting it (across the epoxy grouping) with anhydrous hydrogen bromide dissolved in dioxane. Titration with a standard aqueous sodium hydroxide solution indicates the takeup of hydrogen bromide and consequently the quantity of dieldrin. Unsaturated bonds and other epoxy compounds interfere.

[3] Supplied by Julius Hyman and Company, 1950.

ISODRIN AND ENDRIN

Isodrin and endrin are the endo-endo isomers of aldrin and dieldrin, respectively. Their effectiveness against insects of medical importance has not yet been fully evaluated.

PYRETHRUM AND ALLETHRIN

Ground pyrethrum flowers and their extracts have long been used as insecticides. The principal active constituents are called pyrethrins I and II and cinerins I and II, which occur in different proportions in different samples. In insecticide formulations the mixture of active substances as obtained in extractions with hydrocarbons is frequently called pyrethrins. The material has a rapid paralyzing action on insects but is almost nontoxic to warm-blooded animals. For these reasons it is still used extensively as an insecticide, especially in household sprays.

Good commercial grades of pyrethrum flowers contain 0.7 to 1.6 percent of pyrethrins (total active ingredients) on a dry-weight basis. The standard household spray formerly was prepared by extraction at the rate of 1 pound of ground flowers per gallon of refined kerosene, giving a concentration of about 0.1 percent of pyrethrins. The most highly concentrated commercial preparations contain 20 percent of pyrethrins. These concentrates are used in the preparation of aerosols and sprays.

Allethrin is the coined name for the substantially pure insecticidal chemical *dl*-2-allyl-4-hydroxy-3-methyl-2-cyclopenten-1-one esterfied with a mixture of cis and trans *dl*-chyrsanthemumic acids. The chemical has also been called the allyl homolog of cinerin I and synthetic pyrethrins. Its successful synthesis by chemists of the former Bureau of Entomology and Plant Quarantine after many years of effort was announced in 1949 and was an important milestone in the development of insecticides.

Allethrin, like pyrethrins, is practically harmless to man and animals and appears to be more stable in the presence of light than the natural product. It is slightly less rapid in action, and less toxic to some insects but more toxic to others. It is being produced commercially in increasing quantities and will evidently find an important place in the insecticide field.

PYRETHRUM SYNERGISTS

Several materials have been found that have little toxicity themselves but when mixed with pyrethrins their effectiveness is greatly increased. They are called synergists, or activators. The first one found was sesame oil and later several piperonyl compounds that were still more effective were synthesized. Two of the most important ones are piperonyl cyclonene and piperonyl butoxide. Recently some of the piperonyl derivatives of chrysanthemumic acid, synthesized at the Beltsville laboratory, have shown great promise as synergists. *n*-Octyl sulfoxide of isosafrole (called sulfoxide), *N*-isobutylhendecenamide (IN–930), and propyl isome are also pyrethrum synergists. Of the commercially available materials, sulfoxide appears to be the most effective against lice and piperonyl butoxide against house flies. These

compounds have also shown a less marked synergistic effect with allethrin.

OTHER INSECTICIDES

The materials described previously are the principal insecticides employed in the control of insects of medical importance. Others are used occasionally or for special purposes.

Toxaphene is a chlorinated camphene containing 67 to 69 percent of chlorine. It is an effective mosquito larvicide and has been used against DDT-resistant mosquitoes. It is of value for controlling chiggers and ticks. Toxaphene is also effective against the body louse, but its safety to man when used for this purpose has not been established.

Parathion and EPN, two organic phosphorus compounds, are toxic to many insects but also to warm-blooded animals, and have not been approved for use in controlling household insects. In one South American country, however, parathion has been used, under careful supervision, in a residual spray in houses for controlling DDT-resistant house flies. It is used extensively in the United States for the control of pests on field crops and fruits. EPN is less toxic than parathion to warm-blooded animals and is being considered for use in the control of mosquito larvae resistant to the chlorinated hydrocarbons.

Parathion is a yellowish liquid with a characteristic odor. Its specific gravity is 1.26 and its boiling point is 191° C. or higher at 760 mm. The technical grade has a minimum purity of 95 percent and is often deep brown in color. Its chemical name is *O*,*O*-diethyl *O*-*p*-nitrophenyl phosphorothioate, and its molecular formula $C_{10}H_{14}NO_5PS$.

EPN is a pale-yellow crystalline solid having a melting point of 30° C. The technical material is an amber-colored liquid with a specific gravity of 1.27 at 25°. It is soluble in most organic solvents but practically insoluble in water. Its chemical name is *O*-ethyl *O*-*p*-nitrophenyl phenylphosphonothioate, and its molecular formula $C_{14}H_{14}NO_4PS$.

A number of other organic phosphorus compounds have been synthesized and are being evaluated as insecticides. They include methyl parathion, malathion, para-oxon, TEPP, Diazinon (*O*,*O*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate), Bayer L 13/59 (*O*,*O*-dimethyl 2,2,2-trichloro-1-hydroxyethylphosphonate), and Chlorthion (*O*-(3-chloro-4-nitrophenyl) *O*,*O*-dimethyl phosphorothioate). Some of them are less toxic than parathion and EPN to mammals and may prove more suitable for use in the field of medical entomology.

INSECTICIDE FORMULATIONS

Solutions

In the discussion of insecticide formulations the concentration of solutions is usually given on a weight-per-volume (w/v) basis, but some of the military and Federal specifications are given on a weight-per-weight (w/w) basis. Because the volume of liquids changes with the temperature, it is necessary to state the temperature at which the weight-volume solution is prepared. A temperature commonly

used is 68° F. A 5-percent solution w/v means that each 100 ml. of solution contains 5 grams of the insecticide, and each gallon contains 0.416 pound. On a w/w basis each 100 grams of solution contains 5 grams of insecticide. If the solvent has a density of 0.82 gram per milliliter (the approximate average for kerosene and light fuel oils), and it is assumed that volumes are additive on dissolving, 5 grams of chemical per 100 ml. of solution is equivalent to 5.16 grams per 100 ml. of solvent, 5.92 grams per 100 grams of solution, or 6.29 grams per 100 grams of solvent.

In most large-scale applications of DDT for the control of insects affecting man, solutions in petroleum oils, such as kerosene and fuel oils, are used. DDT is only slightly soluble in such oils, 4 or 5 percent in refined kerosene and 7 to 11 percent in crude kerosene and fuel oils. When a drum of the solution is being prepared, it should be closed and rolled in the sun occasionally during the day. Before use the solution should be examined for undissolved material by probing around in the bottom of the drum with a long stick. If an open-top drum is used, the mixture should be stirred until all the DDT is dissolved. Finely ground DDT will dissolve in a few hours, with stirring, at summer temperature. Mechanical agitators may be used to advantage. If the DDT is lumpy or compacted, the lumps should be broken up and the material passed through a 14- to 18-mesh screen.

Petroleum oil solutions containing more than 5 percent of DDT are obtained by adding suitable auxiliary solvents. To obtain a 10-percent solution, 10 percent of cyclohexanone or 15 to 20 percent of xylene or other suitable solvent may be employed. An auxiliary solvent may also be necessary to obtain a 5-percent solution in refined kerosene. A convenient method is to dissolve the DDT in a minimum of the auxiliary solvent and then dilute to the desired concentration with petroleum oil. In the military-issue 20-percent airplane spray (No. 24, table 3) DDT is dissolved in one of the approved hydrocarbon solvents having a minimum flash point of 160° F. and a distillation range of 365° to 750°. If lower concentrations are needed and not otherwise available, this may be further diluted in the field with fuel oil or kerosene to 5 or 10 percent.

The standard 5-percent DDT spray (No. 23) contains 80 percent of odorless kerosene and 15 percent of alkylated naphthalene having a flash point of 150° F., a distillation range of 300° to 650°, and a specific gravity of 9° to 22° API. The roach and ant residual spray (No. 22) contains 5 percent of DDT and 2 percent of chlordane dissolved in 78 percent of kerosene and 15 percent of alkylated naphthalene with the same specification as above. A Federal space spray (No. 26) contains 1 percent of DDT, 0.1 percent of pyrethrins, and 0.8 percent of piperonyl butoxide in deodorized kerosene. The kerosene is specified to have a minimum flash point of 125° and a distillation range of 350° to 500°. There is also a military specification (No. 25) for an indoor fogging solution that contains 10 percent of DDT, 2 percent of lindane, 83 percent of trichloroethylene, and 5 percent of SAE 50 motor oil. This is dispersed at the rate of 0.5 gallon per 100,000 cubic feet.

The choice of a solvent depends on the method of application and the insecticidal use. For airplane application, solvents of low volatility are needed to reduce evaporation in the air. On the other

hand, light solvents are sometimes desirable for use with refined kerosene for household sprays to permit rapid and complete evaporation from materials on which the spray falls. The flash point should also be considered, as materials with a low flash point may be dangerous under some conditions of storage or transportation. The boiling points and flash points of DDT solvents are shown in table 1.

Lindane and technical BHC are less soluble than DDT in most of the organic solvents. However, this disadvantage is largely offset by the fact that they are more toxic than DDT and may therefore be applied at lower concentrations. Fuel oil alone will dissolve about 2.5 percent of lindane or 6 to 8 percent of BHC (40-percent gamma content) in 1 or 2 days in warm weather, but 10 percent of an auxiliary solvent such as xylene, isophorone, or Sovacide 544–C will hasten the process and may be necessary to insure complete solution in cool weather. Two quarts per acre of these solutions will closely approximate the dosage of 0.1 pound of gamma per acre recommended for mosquito control. With airplane spray units designed to emit only 1 or 2 pints per acre it is necessary to use correspondingly higher concentrations of lindane and BHC to give the desired dosage. Preparation of such concentrations requires the use of increased amounts of auxiliary solvents.

Chlordane, being a liquid and miscible in all proportions with petroleum oils, offers no difficulties in its formulation. For residual sprays a 2-percent solution is usually employed. One military specification (No. 22) covers two types of residual spray for roach and ant control, one containing 2 percent of chlordane and the other 5 percent of DDT and 2 percent of chlordane.

Dieldrin and aldrin solutions have not been covered in military specifications, and for most purposes emulsions or suspensions are preferable. In experiments on mosquito control, fuel oil solutions containing 1.25 and 2.5 percent of dieldrin have been applied by airplane to give dosages of 0.05 and 0.1 pound per acre. At these concentrations an auxiliary solvent is not needed.

Pyrethrum extract is issued as a 20-percent pyrethrins concentrate in refined kerosene and can be diluted to the desired concentration with the same solvent for space sprays. Allethrin is also readily soluble in refined kerosene at the concentrations employed, usually less than 0.5 percent. A space spray for indoor use containing pyrethrins, piperonyl butoxide, and DDT is covered by a military specification, and three space sprays—one containing pyrethrins, synergist, and DDT; one with allethrin, synergist, and DDT (No. 26); and one with pyrethrins and synergist but without DDT—are covered by Federal specifications.

Emulsifiable Concentrates

An emulsifiable concentrate is a concentrated solution of the insecticide in an organic solvent to which an emulsifying agent has been added. It is usually diluted with water to give an emulsion.

One of the first DDT emulsifiable concentrates developed at the Orlando laboratory contained 25 percent of DDT, 65 percent of xylene, and 10 percent of Triton X–100. It was used extensively by both military and civilian workers as a mosquito larvicide and as a residual treatment for mosquito and fly control. It forms a stable

emulsion in hard and even sea water and may be diluted with either of them if soft water is not available. Xylene, however, has a low flash point (about 80° F.); so its handling, transportation, and storage present a fire hazard. A nonexplosive concentrate therefore has been developed with solvents having a higher flash point (140°). This is covered in a Federal specification (No. 8) issued in September and October 1950. The published specification contains a list of 13 commercial hydrocarbon solvents that have been approved by the Quartermaster General. The concentrate is diluted 1 to 24 with water for a mosquito larvicide or 1 to 4 for the standard 5-percent spray for residual applications in buildings and for airplane spraying.

A Federal lindane emulsifiable concentrate (No. 10) contains 20 percent of lindane, 7.5 percent of emulsifier, 40 percent (minimum) of isophorone, and 32.5 percent (maximum) of alkylated naphthalenes. A minimum flash point of 140° F. is specified for the alkylated naphthalenes and also for the concentrate. This concentrate is diluted with water in ratios of 1:3 to give a 5-percent emulsion for airplane spraying, 1:49 to give a 0.4-percent emulsion for outdoor ground spraying, and 1:19 for a 1-percent emulsion for residual spraying in buildings.

A chlordane emulsifiable concentrate (No. 7) calls for 46 percent of technical chlordane in odorless kerosene. It is diluted in ratios of 1:22 to give a 2-percent emulsion for residual sprays in buildings and 1:45 for a 1-percent emulsion for outdoor work.

The dieldrin emulsifiable concentrate (No. 9) contains 18 percent of dieldrin in xylene and has a flash point of only 81° F. It is diluted 1:29 (0.6 percent of dieldrin) for outdoor ground spraying, 1:35 (0.5 percent) for residual treatments in buildings, and 1:59 (0.3 percent) for use as a mosquito larvicide. It may also be diluted 1:5 in fuel oil (3 percent of dieldrin) for airplane spraying.

A commercial aldrin emulsifiable concentrate contains 41.7 percent of the 60-percent aldrin-equivalent solution (see p. 10), which is equal to 25 percent of aldrin. The solvent is specified as a petroleum hydrocarbon having a minimum flash point of 115° F. The concentrate is diluted 1:37 (about 0.6 percent of aldrin) for ground spraying and use as a mosquito larvicide and 1:45 (about 0.5 percent) for outdoor residual spraying.

Wettable Powders

A wettable, or dispersible, powder is prepared by grinding or blending the insecticide with a readily wettable inert dust and adding a suitable wetting or wetting-dispersing agent as necessary.

Specifications have been prepared at the Orlando and Beltsville laboratories for wettable powders containing 75 percent of DDT (No. 30), 75 percent of lindane (No. 29), and 50 percent of dieldrin (No. 28). Water is added to these materials to give suspensions containing about the same concentrations of insecticide as for emulsions (pp. 14-15), and they are used for much the same purposes.

Several laboratories have attempted to develop colloidal or very finely divided suspensions of DDT such as are obtained when a solution of DDT in a water-miscible solvent is added to water. Such formulations remain in suspension much better than the ordinary wettable powders, which require continuous agitation to prevent

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settling, and they would be of special value as mosquito larvicides. However, a satisfactory formulation for practical use has not yet been produced.

Dusts and Dusting Powders

DDT dusts have been used widely for louse control and also to some extent against other insects of military importance, such as mosquito larvae, cockroaches, ticks, and chiggers. In civilian health programs their greatest use at present is for the control of rat fleas in the natural habitats of their hosts. For all these uses 5- or 10-percent dusts are usually employed.

Technical DDT, because of its low melting point, is difficult to grind alone to produce a powder sufficiently fine for direct mixing with a diluent. However, it can be ground with a diluent such as pyrophyllite or talc, or the diluent can be impregnated or blended with a solution of DDT in a volatile solvent. By these means dusts containing 25 to 75 percent of DDT can be produced and reduced to the desired concentration by mechanical mixing. The wettable powder can also be diluted in a similar manner and applied as a dust.

The principal military use for DDT powders is in the control of lice by application to the clothing or hair. Specifications have been issued for two powders, one containing 10 percent in pyrophyllite (No. 5) and the other containing in addition 0.2 percent of pyrethrins and 1 percent of piperonyl butoxide (No. 4). After the discovery of DDT-resistant lice in Korea and Japan, a 1-percent lindane powder was developed (No. 3). These materials are also intended for limited use by individuals against fleas, bed bugs, and other crawling insects.

Another specification (No. 6) provides for pyrethrum powders for louse and flea control. One powder contains 0.2 percent of pyrethrins and 2 percent of the synergist sulfoxide together with an ovicide, an antioxidant, and a powder conditioner. Another powder contains in addition 0.3 percent of allethrin. The louse powders are packaged in 2-ounce containers for individual use and larger containers for mass dusting.

Granulated Insecticides

Granulated insecticides have been developed to enable more efficient treatment of mosquito and sand fly breeding places protected by dense vegetative cover. Granular bentonite and attapulgite of 16/30 and 30/60 mesh have been used in tests. Little or none of the granular material is lost through adherence to the foliage, whereas the loss is usually high with sprays and dusts. Granulated insecticides may also be applied satisfactorily under weather conditions that would preclude the use of sprays or dusts.

In experimental studies some of the materials were prepared in a concrete mixer by spraying a solution of the insecticide in benzene onto the carrier while the mixer was rotating. Granulated BHC was also prepared by spraying the carrier with melted BHC of 36-percent gamma content, which eliminated the need of a solvent with this low-melting material. Concentrations ranging from 2.5 to 8 percent were prepared for different purposes.

Liquefied-Gas Aerosols

The high-pressure pyrethrum aerosol was devised by L. D. Goodhue

and W. N. Sullivan of the former Bureau of Entomology and Plant Quarantine and later developed in cooperation with the Army and Navy for greater economy in the use of pyrethrum. The insecticide was dissolved in liquefied Freon-12 (dichlorodifluoromethane) and confined in refillable seamless steel cylinders, or "bombs," which have a capacity of 1 pound. When the liquefied gas containing the insecticide was released through its own pressure (82 pounds per square inch at 68° F.), the insecticide was dispersed in the air in very fine particles, providing an effective and convenient method of destroying mosquitoes in tents, barracks, billets, bomb shelters, and other confined spaces. Later DDT was added to the formula. The specification issued in January 1950 (No. 1) contains 0.4 percent of pyrethrins, 3 percent of DDT, cyclohexanone and hydrocarbon oil 5.0 to 5.5 percent each, and Freon-12 to make 100 percent.

After World War II it was found that a 50–50 mixture of Freon-11 (trichloromonofluoromethane) and Freon-12 provided a satisfactory aerosol propellent having a pressure of less than 55 pounds per square inch at 70° F., which permitted the use of a low-cost tinplate container (fig. 1). Two types of low-pressure aerosols in 12-ounce containers have been used by the Armed Forces, one containing 0.6 percent of allethrin (No. 2) and the other 0.4 percent of pyrethrins (2 percent of a 20-percent extract) plus 1 percent of piperonyl butoxide. Both types contain 2 percent of DDT, 5 percent of alkylated naphthalenes, 5 to 7.4 percent of deodorized kerosene, and 41.2 to 42.5 percent each of Freon-11 and Freon-12. A valve delivery rate of 0.65 to 1.25 grams per second at 80° is specified.

FIGURE 1.—A low-pressure aerosol dispenser.

REPELLENTS

The standard mosquito repellents adopted by the Armed Forces during World War II were dimethyl phthalate, 2-ethyl-1,3-hexanediol, Indalone, and 6–2–2 and 1–1–1 mixtures of these three materials. They were covered in a joint Army and Navy specification and amendments (No. 18). A military specification (No. 21) issued in July 1952 covered two revised Orlando mixtures (M–2020 and M–2043), one containing 40 percent of dimethyl phthalate and 30 percent each of 2-ethyl-1,3-hexanediol and dimethyl carbate and the other, 30 percent of propyl *N,N*-diethylsuccinamate in place of dimethyl carbate.

The first repellent developed for the treatment of clothing for protection against chiggers and adopted by the Army contained 45 percent each of benzyl benzoate and dibutyl phthalate and 10 percent of an emulsifier (No. 19). Later a clothing treatment was developed at the Orlando laboratory for protection against several kinds of insects. This is known as formula M–1960 and contains 30 percent each of *N*-butylacetanilide, 2-butyl-2-ethyl-1,3-propanediol, and benzyl benzoate plus 10 percent of an emulsifier (No. 20).

These and other repellent materials are discussed on pages 74–80. Their approximate specific gravities and melting and boiling points are shown in table 2.

TABLE 2.—*Specific gravity and melting and boiling points of various repellents*

Repellent	Specific gravity [1]	Melting point	Boiling point
		°C.	°C.
Benzyl benzoate	1. 11	[2] 18	324
N-Butylacetanilide	. 99	[2] 22	277–281
N-Butyl-4-cyclohexene-1,2-dicarboximide	1.09 (28°/28°)		119–121
2-Butyl-2-ethyl-1,3-propanediol		40–42	
Dibutyl phthalate	1. 05		340
Dimethyl carbate	1.16–1.17 (35°/4°)	70	
Dimethyl phthalate	1. 19		282
2-Ethyl-1,3-hexanediol	. 94		244
Hendecenoic acid (undecylenic)	. 91 (24°/4°)	24	[3] 295
Hexyl mandelate	1. 02 (28°/28°)		
Indalone	1. 06		110–115
N-Propylacetanilide		47	222–225
Propyl *N,N*-diethylsuccinamate	1. 01 (15°/15°)		

[1] When no temperature is given, it is understood to be 20°/4° C.
[2] Setting point.
[3] Decomposes.

MILITARY-ISSUE ITEMS

Insecticides and repellents for use in controlling insects are supplied to the Armed Forces in the forms listed in table 3. The Federal and military specification numbers and Federal stock numbers are shown. All items are being converted to Federal stock numbers, and where this has not been accomplished no stock number is given. Similar preparations can also be obtained from commercial sources. The equipment for use in applying the insecticides is listed in table 4.

TABLE 3.—*Insecticides and repellents used by the Armed Forces in the control of insects affecting man*

Item No.	Specification: Title	Specification: No.	Unit of issue	Federal stock No.	Active ingredients (figures in percent)
	AEROSOLS				
1	Insecticide aerosol (dichlorodifluoromethane solvent), in dispensers or charging cylinders.	MIL–I–2260	1 lb		Pyrethrins 0.4, DDT 3.
2	Insecticide, aerosol, low pressure (12-ounce dispenser).	O–I–508, Type I	12 oz	6840–254–8770	Allethrin 0.6, DDT 2.
	DUSTS AND DUSTING POWDERS				
3	Insecticide, lindane, powder, dusting	MIL–I–11490A	2 oz	6840–242–4217	Lindane 1.
			5 lb		
			25 lb	6840–242–4219	
4	Insecticide powder, DDT and pyrethrins.	MIL–I–11253 (QMC).	2 oz		DDT 10, pyrethrins 0.2, piperonyl butoxide 1, isopropyl cresols 0.25.
			5 lb		
5	Insecticide powder, dusting	O–I–578	2 oz	6840–242–4229	DDT 10.
			5 lb	6840–240–2540	
			25 lb	6840–252–3002	
6	Insecticide powder, pyrethrins and synthetics.	MIL–I–11355A, Type II.	2 oz		Pyrethrins 0.2, sulfoxide 2, 2,4-dinitroanisole 2, isopropyl cresols 0.1.
			4 lb		
			20 lb		

TABLE 3.—*Insecticides and repellents used by the Armed Forces in the control of insects affecting man*—Continued

EMULSIFIABLE CONCENTRATES

Item No.	Specification: Title	Specification: No.	Unit of issue	Federal stock No.	Active ingredients (figures in percent)
7	Insecticide, chlordane (concentrate, water emulsifiable).	MIL-I-16424A	5 gal		Chlordane 46.
8	Insecticide, DDT emulsifiable concentrate, nonexplosive solvent.	O-I-558a	5 gal	6840-242-4210	DDT 25.
9	Insecticide, dieldrin, emulsifiable concentrate.	MIL-I-11425 (QMC).	5 gal	6840-264-9043	Dieldrin 18.
10	Insecticide, lindane (emulsifiable concentrate).	O-I-533	5 gal 1 gal	6840-242-4213	Lindane 20.
11	Insecticide, spray, delousing	MIL-I-1909A	1 gal	6840-253-3893	DDT 6, benzyl benzoate 68, benzocaine 12.

INSECTICIDE INGREDIENTS

Item No.	Specification: Title	Specification: No.	Unit of issue	Federal stock No.	Active ingredients (figures in percent)
12	Dichlorodiphenyltrichloroethane (DDT).	O-D-370, Grade B	5 lb 25 lb	6840-242-4221 6840-242-4222	
13	Fuel oil, burner Fuel oil, diesel	VV-F-815 VV-F-800	 1 gal	 9140-286-5297	
14	Kerosene, water-white (for use in insecticide).	MIL-K-3128			
15	Methyl bromide (liquefied)	O-M-261, Type B	20 ml 1 lb 150 lb	6840-270-9995 6840-270-9996	
16	Paradichlorobenzene, technical (dichlorobenzene, para).	O-P-99	1 lb 100 lb		
17	Sodium arsenite solution	MIL-S-15983A	30 gal		Arsenic trioxide 54.5.

REPELLENTS

18	Repellent, insect	JAN-R-249: Type A, Grade 1	2 oz	6840-246-6167	Dimethyl phthalate 60, 2-ethyl-1,-3-hexanediol 20, Indalone 20.
		Type B	1 gal		Dimethyl phthalate 100.
19	Repellent, insect, clothing treatment	MIL-R-10045	1 gal	6840-246-6435	Benzyl benzoate 45, dibutyl phthalate 45.
20	Repellent, insect, clothing treatment, formula M-1960.	MIL-R-12123A	1 gal	6840-270-6200	2-Butyl-2-ethyl-1,3-propanediol 30, benzyl benzoate 30, *N*-butylacetanilide 30.
21	Repellent, insect, M-2020 and M-2043	MIL-R-249B, Type I.	2 oz	6840-285-1179	Dimethyl phthalate 40, 2-ethyl-1,-3-hexanediol 30, dimethyl carbate 30.

SOLUTIONS

22	Insecticide, chlordane; and insecticide, chlordane and DDT (liquid, residual roach and ant control).	MIL-I-15051A: Type I	1 gal		Chlordane 2.
			5 gal		
		Type II	1 gal	6840-240-2538	Chlordane 2, DDT 5.
23	Insecticide, DDT (solution, residual effect).	O-I-531a	5 gal	6840-253-3892	DDT 5.
24	Insecticide, DDT (20-percent solution).	MIL-I-1908A	55 gal	6840-00-19003	DDT 20.
25	Insecticide, DDT and lindane, indoor fogging.	MIL-I-12262 (QMC)	5 gal	6840-270-9972	DDT 10, lindane 2.
26	Insecticides, liquid, space spray	O-I-551a, Type II	1 gal	6840-281-4225	Allethrin 0.16, piperonyl butoxide 0.8, DDT 1.
27	Insecticide, thiocyanates and DDT	MIL-I-16604A (Ships): Type L	1 gal		Lethane 2.5, DDT 1.5.
		Type T	1 gal		Thanite 1.25, DDT 1.5.

TABLE 3.—*Insecticides and repellents used by the Armed Forces in the control of insects affecting man*—Continued

WETTABLE POWDERS

Item No.	Specification		Unit of issue	Federal stock No.	Active ingredients (figures in percent)
	Title	No.			
28	Insecticide, dieldrin 50 percent, water-dispersible powder.	MIL–I–11374 (QMC).	15 lb	6840–281–2059	Dieldrin 50.
29	Insecticide, lindane (water-dispersible powder).	O–I–535	15 lb	6840–227–1840	Lindane 75.
30	Insecticide, 75 percent DDT water-dispersible powder.	O–I–568	15 lb 25 lb	6840–240–2539	DDT 75.

TABLE 4.—*Equipment used by the Armed Forces in applying insecticides for the control of insects affecting man*

Item No.	Specification		Stock No.		Additional description
	Title	No.	Army [1]	Navy	
1	Applicator, fog, insecticidal	MIL–A–898A			Thermal aerosol generator.
2	Chamber, fumigation, methyl bromide, non-portable.	MIL–C–2397	66–C–910 (4230–171–1311).		
3	Chamber, fumigation, methyl bromide, portable.	MIL–C–2398, Type I	66–C–925 (4230–171–1312).		Gasoline-driven.
4	Duster, insect, hand, rotary blower type, paris green or powder, 5- to 10-pound capacity.	MIL–D–11088A	41–3115.500.100	41–D–4503	
5	Duster, powder, delousing, compressed air.	MIL–D–1837			
6	Duster, powder, insecticide	MIL–D–2388A (QMC)	41–3117.500.100	41–D–4510	Plunger-type hand-duster.
7	Outfit, delousing, gasoline-engine driven.	MIL–O–2457	66–0–800 (4230–224–8636).		Power duster.
8	Sprayer, insect, knapsack, plunger type, 2-gallon capacity.		41–7839.350.020		Cylindrical pressure sprayer.
9	Sprayer, insecticide, skid-mounted, gasoline-driven, piston pump type.	MIL–S–12511 (QMC)	40–9040.600.300		
10	Sprayer, liquid, insecticide continuous spray, 2⅔ quarts with spray-control valve.	MIL–S–12119 (QMC)	41–7839.700.600	41–8–4120	Hand sprayer.

[1] Federal stock numbers in parentheses.

CONTROL OF MOSQUITOES

As a result of research at the Orlando laboratory during 1943, DDT was recommended to the Armed Forces for the control of mosquitoes. This new insecticide proved outstandingly superior to other materials as a larvicide, in space sprays for large-scale use against the adults, and as a residual treatment for buildings and vegetation to destroy mosquitoes as they alighted or rested on the sprayed surfaces. Later some of the other chlorinated hydrocarbons, such as benzene hexachloride, dieldrin, and toxaphene, were found to be highly toxic to mosquitoes, but they came into only limited use until some mosquito populations became resistant to DDT.

Except against these resistant mosquitoes, DDT has continued to be the most widely used insecticide in the control of both anopheline and culicine mosquitoes. Since it is a contact as well as a stomach poison and is soluble in a number of organic solvents, including petroleum oils, it can be used in various ways that are not practical with larvicides such as paris green. The fact that it is effective in very small amounts simplifies transportation and supply problems, which are especially important in combat areas. It is now used by the Armed Forces in four forms—(1) in petroleum oils or other hydrocarbons, (2) as concentrates for use in preparing aqueous emulsions, (3) in dusts with an added wetting agent for aqueous suspensions, and (4) in dusts without a wetting agent.

Resistance to DDT was found among populations of salt-marsh mosquitoes in several counties in Florida where this insecticide had been used for several years. A similar development was reported for several species found in irrigated pastures in California, for a domestic species of *Culex* in Italy, and for several species of *Anopheles* in different countries. This problem is expected to be of increasing importance, judging by the spread of DDT resistance in the house fly and the body louse, and means for combating it must be considered.

Although this discussion of mosquito control is limited to the use of insecticides, measures for permanent elimination of breeding areas should be undertaken whenever possible. The threat of decreasing effectiveness of chemical control emphasizes this principle.

CONTROL OF MOSQUITO LARVAE

DDT Sprays

Technical DDT in an oil spray or in an aqueous emulsion of an oil solution is the most widely used mosquito larvicide. In an oil spray it is usually dissolved in kerosene or fuel oil in concentrations ranging from 5 to 1 percent or less. When available, No. 2 fuel oil is employed by the Armed Forces for outdoor use. Concentrated solutions in other solvents are sometimes made and diluted with kerosene or fuel oil as needed (see p. 13).

Larvicides are generally applied with sprayers. Owing to the remarkable larvicidal action of DDT, very little spray is needed, and this must be realized to take full advantage of the potential saving in materials and labor. Oil without DDT is applied at 10 to 25 gallons per acre for control of culicine larvae. Comparable results can be obtained with 5 quarts per acre of a 1-percent DDT solution or 1 quart

or even less of a 5-percent solution when properly dispersed. To obtain coverage with such small amounts it is necessary to use a slow delivery of a fine mist, and most of the ground equipment now available, except the fog or aerosol machines, cannot be adjusted to give uniform distribution of minimal quantities.

For small breeding places the cylindrical, hand-pumped compression sprayer (fig. 2) is generally used (No. 8, table 4). A militar

FIGURE 2.—A 2-gallon compressed-air sprayer.

model is provided with four different nozzles—solid-stream, fan-spray, cone-spray, and atomizing. The orifice diameters in the spray heads are not to exceed 0.04 inch. This type of sprayer is operated at a pressure of 20 to 30 p. s. i. Cylindrical compression sprayers of 3-gallon capacity were formerly referred to in the Army as decontamination type sprayers and also as Loftstrand sprayers.

In civilian public-health work similar sprayers have been modified to provide the pressure by means of a small refillable carbon dioxide tank attached to the spray cylinder. In another modification a valve is installed at the top of the cylinder so that it can be filled with air

from a high-pressure reservoir or by an air compressor. Another model has a separate air cylinder that is charged as needed from an air pump or other source of compressed air.

With a fine spray nozzle and with the aid of a breeze sufficient to give a swath width of 50 feet, effective coverage can be obtained with 5 or 6 quarts of spray per acre, although larger quantities should be used if needed. Since 0.1 pound or even less of DDT per acre is sufficient, the concentration should be reduced to 1 percent to give this dosage. Under favorable conditions good control over a swath width of several hundred feet has been obtained with a finely atomized oil spray containing 5 percent of DDT at the rate of 1 to 2 quarts per acre. In difficult places several gallons of spray may be required to obtain distribution, but in order to reduce labor and transportation of materials an effort should always be made to apply minimal amounts.

A 25-percent DDT emulsifiable concentrate (p. 14) developed at Orlando formed stable emulsions with many kinds of water, including sea water. Later, at the request of the Armed Forces, a 25-percent concentrate having a higher flash point was developed to reduce fire hazards in storage or during shipment.

After dilution, water emulsions are applied in the same manner as oil solutions. A mixture of 1 part of the 25-percent concentrate and 4 parts of water gives a 5-percent spray, and 1 part of concentrate with 24 parts of water gives a 1-percent spray. Such emulsions are very effective against mosquito larvae when dispersed throughout the water, but when sprayed as a fine mist, the material has a tendency to remain on or rise to the water surface. For this reason the dosage is usually based on the amount per acre rather than on parts per million.

Emulsions dispersed in water are somewhat more toxic to culicine larvae than equivalent dosages of DDT in oil on the water surface, but they are also more toxic to fish. Therefore, oil solutions are advocated for use on waters containing fish, particularly for the control of anopheline larvae. However, the amount of DDT in emulsion required to kill mosquito larvae is well below the amount toxic to most fish. If the quantity applied is carefully controlled, it may be used where for logistic reasons an emulsion is particularly desirable. Dusts may also be used.

Under some conditions large breeding areas, such as extensive roadside borrow pits, can be treated with power sprayers mounted in motor vehicles. Various types of power equipment are used for this purpose, as well as for the control of adult mosquitoes (see pp. 32–40). The use of airplanes for mosquito control is discussed on pages 42–55.

A household hand sprayer is convenient for treating small scattered breeding places. An oil squirt gun or even a dropping bottle or eye dropper can be used for the same purpose. A few drops of 5-percent DDT solution with good spreading qualities is sufficient for treating a pool of water 10 feet square.

Effective treatment is possible with small amounts of spray if the equipment is adjusted to produce a fine mist and if weather conditions are favorable. If adequately distributed, 5 quarts of a 1-percent DDT spray per acre is usually sufficient, but a lower concentration should be used if more spray is needed for coverage. A dosage of

0.1 pound of DDT per acre is recommended for initial trials. This amount is contained in approximately 0.4 pint (6.4 fluid ounces) of a 25-percent concentrate. By comparison, 25 times this amount of a 1-percent oil solution (5 quarts), or 300 to 600 times as much oil alone would be required for equivalent results. The great savings in transportation is apparent.

When the emulsion is dispersed throughout the water, 0.1 pound per acre is equal to 0.1 p. p. m. in water 4.43 inches deep. Heavier dosages, up to 1 p. p. m. in still pools, will prevent breeding for several weeks. Where fish are present, heavy dosages are not recommended, but there are many situations, such as temporary pools, shell holes, log ponds, and some borrow pits, where mortality of fish is not a problem.

A quick-breaking oil emulsion rather than a stable one is sometimes employed when a surface concentration of the larvicide is desirable. It can be prepared readily by reducing the amount of emulsifier to about 3 percent or by adding up to 4 parts of fuel oil or kerosene to the standard 25-percent DDT emulsifiable concentrate.

Wettable powders containing either 50 or 75 percent of technical DDT are available. When mixed with water they form suspensions, which may be used for spraying mosquito-breeding places. When properly dispersed, suspensions are very effective larvicides, but heavier dosages are needed than for emulsions or oil solutions. The principal advantages of wettable powders over emulsifiable concentrates or oil solutions are that they are in a more concentrated form and are packaged dry for transportation. There is no fire hazard or solvent problem, and the water is obtained near the site of operations. They may also be diluted with a dry carrier and applied in dusts when this method of dispersal is advantageous. The chief disadvantages are that they require frequent agitation to remain in uniform suspension and they are very abrasive to gear pumps when used in power sprayers.

DDT Dusts

DDT dusts are highly effective against anopheline larvae, and are particularly useful where long-distance drifting is needed to treat wide breeding areas. Dusts also penetrate thick vegetation better than liquids, provided the vegetation is dry. In localities where adults habitually rest on vegetation around the breeding places, the dust adhering to the plant cover provides additional adult control. Rather heavy dust applications to abandoned septic tanks, cisterns and cellars, or to rubble-filled areas, vehicle dumps, and old tires have also been effective in military control of various species of disease-bearing *Aedes* and *Culex*.

DDT dust is much more toxic than paris green, which was previously used extensively for malaria-vector control. A dosage of 0.1 pound or less of DDT per acre is sufficient under usual conditions. This requires 1 pound or less of a 10-percent dust, or 10 pounds of a 1-percent dust. Because of the physical properties of technical DDT, the preparation of a good dust requires special equipment for grinding with an inert diluent, such as talc. For this reason it is not feasible to prepare the original mixture in the field. A 10-percent dust (No. 5, table 3) is chiefly used in the control of lice. Since this con-

centration is considerably higher than is usually needed for mosquito control, the dust should be further diluted. This can be done in the field with improvised mixing equipment if a suitable diluent is available.

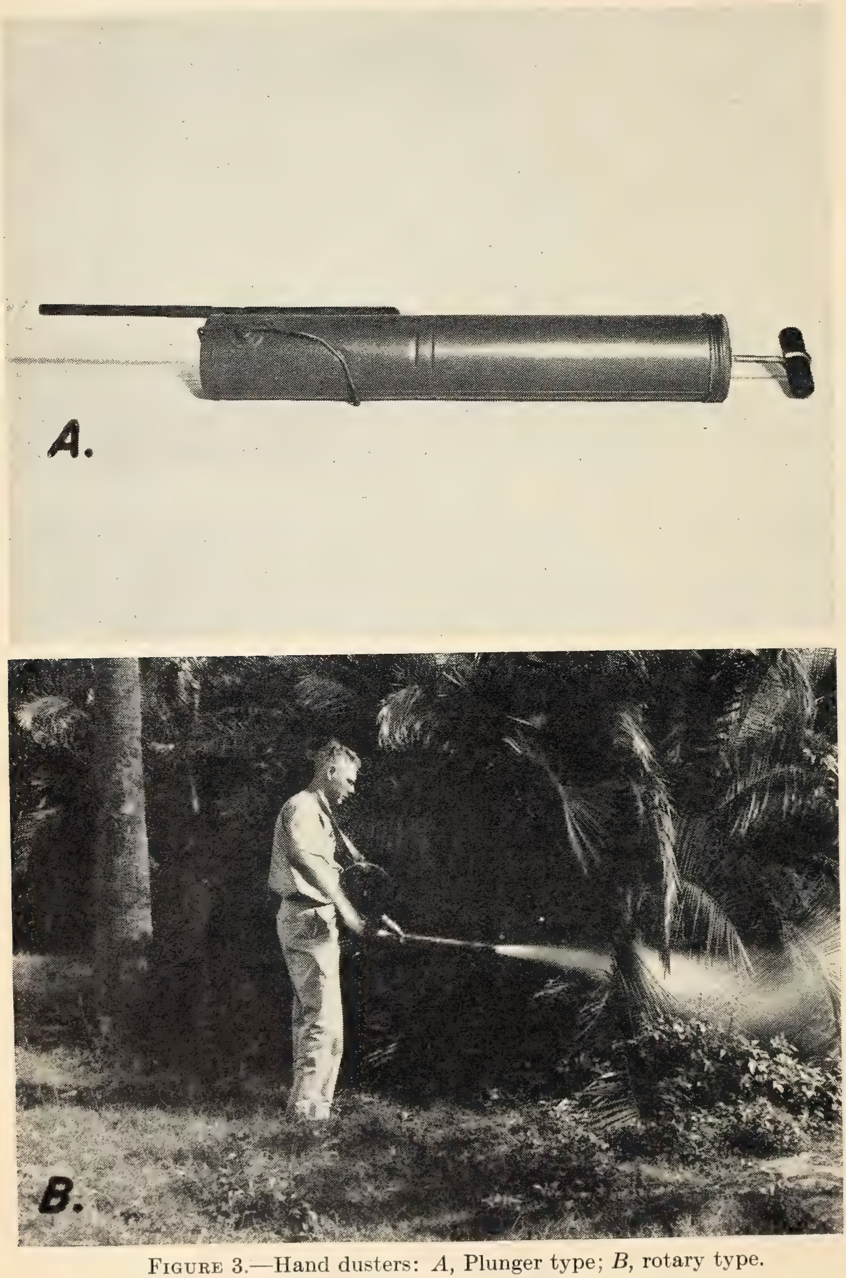

FIGURE 3.—Hand dusters: *A*, Plunger type; *B*, rotary type.

Two hand-operated dusters (fig. 3) are available as military-issue items. One is of the plunger type (No. 6, table 4) and the other, a larger one, called a rotary duster (No. 4), has a fan and a shoulder strap. In water shallow enough for wading the dust can be dispersed in swaths. When the water is deeper, the dusting may be done from the upwind shore or from a boat. With a light, favorable breeze a wide swath can be covered.

Other Larvicides

Several chlorinated hydrocarbons other than DDT, including chlordane, benzene hexachloride, lindane, dieldrin, and heptachlor (see pp. 6–10), are highly toxic to mosquito larvae, and specifications for most of them have been prepared covering formulations for certain types of insect control for use by the Armed Forces. Several of the organic phosphorus compounds are also effective larvicides.

In laboratory tests EPN and parathion, followed by dieldrin, were the most toxic to the larvae of several species. In field tests EPN, parathion, dieldrin, and lindane have generally been the most effective.

Table 5 gives the approximate lethal dosages of various larvicides against the common malaria mosquito, the yellow-fever mosquito, the southern house mosquito, the salt-marsh mosquitoes, and mixed populations of subarctic *Aedes*.

In the laboratory tests acetone-water suspensions were used under fairly uniform conditions. The field tests were run on small measured plots with either oil solutions or emulsions.

In some tests the highest dosages gave a kill of less than 95 percent, and the minimum lethal dosage was estimated from the kill obtained. Even in the laboratory the results varied greatly with different lots of larvae. In eight tests with DDT, for example, the minimum lethal dosages against the malaria mosquito ranged from 0.0025 to 0.01 p. p. m.

Since some of the figures in the table are based on only one or two tests the data are not strictly comparable and may be slightly misleading as to relative effectiveness. The records do show, however, that all the compounds in this group are highly toxic to more than one species of mosquitoes and any of them may be worth considering for use in specific problems. Important factors that must be considered are the hazards of the chemicals to the operators, effects on fish and wildlife, and relative cost against different species.

In the coastal areas in Florida where resistance to DDT was found among salt-marsh mosquitoes, most of the larvicides in table 5 were tested with a view to selecting satisfactory substitutes. Lindane, dieldrin, heptachlor, and EPN gave favorable results in both laboratory and field tests. Chlordane had a low minimum lethal dosage in laboratory tests but was less effective in field tests. Aldrin showed a high order of toxicity in some field tests and should be tested further. Parathion and EPN were the most toxic materials tested in the laboratory, but in several field tests parathion showed the same toxicity as toxaphene. In other series parathion was as effective as EPN and malathion.

TABLE 5.—*Approximate minimum lethal dosages (95 to 100 percent kill) of various larvicides against several species of mosquitoes*

Larvicide	Laboratory tests (p. p. m.)					Field tests (pounds per acre)		
	Common malaria	Yellow-fever	Southern house	Salt-marsh spp.	Subarctic *Aedes*	Common malaria	Salt-marsh spp.	Subarctic *Aedes*
DDT	0. 01	0. 01	0. 02	0. 025	0. 025	0. 0125	0. 1	0. 15
Chlordane	. 01	. 025	. 025	. 02	. 05	. 1	. 1	. 4
Lindane	. 03	. 05	. 05	. 02	. 03	. 08	. 035	
BHC (technical)	. 2					. 4	. 35	. 3
Dieldrin	. 005	. 01	. 01	. 01	. 03	. 007	. 035	
Aldrin	. 025	. 025	. 025	. 015		. 25	. 025	
Toxaphene	. 01	. 025	. 025	. 02		. 1	. 1	. 4
Heptachlor	. 025	. 025	. 075			. 01	. 025	
TDE	. 01	. 025	. 025	. 15	. 05	. 2		. 5
Methoxychlor	. 1	. 1	. 05		. 03	. 4		. 15
llethrin	. 2	. 2	. 1			. 2		
Pyrethrins	. 1	. 05	. 025			. 2		
Parathion	. 0015	. 0025	. 0025	. 005	. 01	. 025	. 05	
EPN	. 0025	. 004	. 004	. 0025		. 004	. 01	
Malathion	. 025			. 05		. 5	. 05	

Against DDT-resistant mosquito larvae 0.05 to 0.1 pound of lindane per acre, dieldrin at the same dosage, and toxaphene at 0.1 to 0.2 pound per acre are recommended. However, toxaphene is highly poisonous to fish and should not be used where they are important. EPN and parathion have not yet been approved for use by the Armed Forces, but may be considered in the future for special situations, such as for the control of mosquito populations that show increased resistance to all the chlorinated hydrocarbons. Their use as larvicides has also been suggested to obviate the development of resistance to the hydrocarbons and thus permit continued use of the latter as adulticides.

Prehatching Treatments

One method of mosquito control made possible by the long-lasting qualities of DDT is the prehatching (sometimes called preflooding) treatment of both fresh-water and salt-marsh areas where large broods of *Aedes* mosquitoes develop. The dosage is usually about 1 pound of DDT per acre, but varies under different conditions from ½ to 2 pounds or even more, and the applications are made when the areas are either flooded or dry. Such treatments have been effective sometimes over an entire season during which repeated floodings occurred. With the mountain and subarctic species of *Aedes* that have only one annual brood, the eggs of which hatch as soon as pools are formed by melting snow, control has been obtained by applications to the surface of the snow in the late spring or even to the dry or wet ground before snowfall the previous season.

In one experiment a large area in Alaska was treated by airplane with DDT-oil sprays several times during two summers. There was a marked reduction in breeding during the second and third years, owing apparently to the residual action of DDT.

For prehatching treatments of wet or dry ground the wettable powder is perhaps the most effective, although all the other DDT formulations have also proved satisfactory. For application to snow 10- or 20-percent DDT dust or dry wettable powder is preferred where dusting equipment is available and strong winds do not interfere.

It is now believed that larvicidal treatments, especially prehatching, may cause resistance to develop more rapidly than spraying directed against the adults only. This possibility should be carefully considered before extensive larvicidal programs are undertaken where repeated treatments year after year are likely to be required.

Other Types of Application

Gelatin capsules containing an emulsifiable concentrate of DDT or other larvicide have been used to a limited extent in mosquito control, especially for treating small, scattered pools. The capsules are thrown by hand into the breeding places, where they swell and burst after contact with the water. DDT cakes prepared with plaster of paris and small insecticide pellets prepared with a clay carrier have been used in a similar manner. Granular bentonite impregnated with a larvicide, which has been used in airplane work (p. 50), may also be broadcast in breeding places by hand or with a hand seeder.

Other methods of applying mosquito larvicides include the use of drip cans and sawdust soaked with an oil solution of DDT or other

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insecticide. The sawdust is either broadcast by hand or placed in bags and thrown into the breeding places, sometimes before flooding occurs. However, these methods have limited practical use, as the duration of effectiveness is uncertain and they are not always so economical as they may seem. Drip cans require frequent servicing, and an excessive amount of larvicide is expended to maintain an effective dosage. A much smaller quantity poured at the same points every 7 to 10 days will prevent the emergence of adults and require no more labor.

CONTROL OF ADULT MOSQUITOES

In many respects the destruction of adult mosquitoes is even more important in time of war than in peacetime. Troops entering an area where malaria and other mosquito-borne diseases are prevalent may be exposed for weeks to infected vectors even though operations for control of larvae are initiated at once. On the other hand, rapid destruction of adult mosquitoes will prevent transmission of these diseases. Ways of destroying adult mosquitoes have therefore been given much attention, and effective methods are now in use that were never employed before World War II.

The work on adult mosquito control has been along three major lines: (1) The development of sprays and equipment for destroying them on a large scale out of doors, (2) the development of residual treatments for buildings and other places where mosquitoes congregate or alight, and (3) the use of aerosols and concentrated sprays for indoor use.

Outdoor Space Sprays

Before DDT was available, pyrethrum sprays were frequently used for the temporary protection of outdoor gatherings, such as picnic parties and baseball crowds. In recent years DDT and other synthetic organic compounds have been employed for destroying mosquitoes over large areas. Airplane spraying is particularly well adapted to this purpose (see pp. 42–55). Spraying with ground equipment has also proved useful for reducing mosquitoes in small areas. It is an economical and practical means of protecting troops in temporary campsites or in small isolated installations. Some of the larger machines are also useful for treatment of larger camps when the maintenance of spray planes is not feasible or where spot spraying to meet localized infestation is needed frequently.

Many species of mosquitoes do not fly far from their resting places during the day. Their destruction in small areas may therefore provide excellent protection even when others are numerous in surrounding untreated areas. At dusk the treated areas may be reinvaded so that additional treatment is required.

Hand-operated equipment.—Finely atomized sprays containing 5 percent of DDT in kerosene have given excellent control of anopheline and various kinds of pest mosquitoes. One means of dispersal over a small area is a DeVilbiss-type paint sprayer operated from a hand-pumped or other type of pressure tank (fig. 4). In nearly still air the spray is dispersed in 20-foot swaths at the rate of ½ to 1 pint per acre. The 2-gallon compression cylinder with a fine nozzle may be used in a

FIGURE 4.—Outdoor spraying with a DeVilbiss paint sprayer.

similar way. Even with the finest nozzle it is difficult to cover an acre adequately with less than 5 or 6 quarts because of the rapid discharge and the coarse droplet size.

Liquefied-gas aerosols.—The standard DDT-pyrethrum aerosol bomb may be used to reduce mosquitoes in thickly wooded areas in the same way as described for space sprays. The aerosol is released as the operator walks back and forth along parallel swaths about 20 feet apart. Because the particles tend to rise and the mosquitoes usually rest in the brush close to the ground, it is best to tie the bomb to a stick and hold it within a few inches of the ground. The contents of a 1-pound bomb (No. 1, table 3) have controlled salt-marsh mosquitoes over an acre or even more, where it was possible to take advantage of a slight air movement to drift the aerosol slowly through the vegetation.

Power hydraulic sprayers.—For treating large areas power-operated sprayers and other types of power equipment may be employed. They are used chiefly for the treatment of occupied areas and installations where roads or streets are available along which the vehicles carrying the equipment may be driven. The spray is released on the downwind side of the street, and moderate breezes up to about 10 m. p. h. aid the drifting of the fine droplets across country.

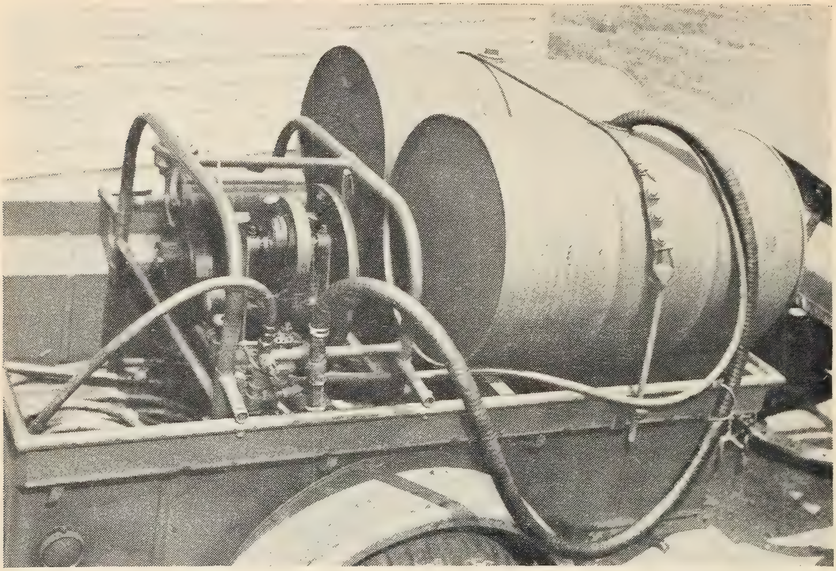

FIGURE 5.—Power hydraulic sprayer mounted in a trailer.

A portable hydraulic sprayer (fig. 5) that is skid mounted, weighs about 195 pounds, and has a piston pump operated by an air-cooled gasoline engine developing 1¾ hp. at a speed of 2,240 r. p. m. is a military-issue item (No. 9, table 4). The spray gun is furnished with four disks having openings from $\frac{1}{16}$ to $\frac{7}{64}$ inch in diameter. The pump is required to have a minimum capacity of 3 gallons per minute at a pressure of 300 p. s. i. when operating at a speed not over 150 r. p. m. and to have a regulator adjustable for 0 to 500 p. s. i. A ¾-inch intake hose is supplied to draw the spray solution from a separate tank or drum. At the pressure indicated the droplets are finely broken up and remain air-borne long enough to give swath widths up to 600 feet under favorable atmospheric conditions. Based on this width of swath and an output of 3 gallons per minute of a 5-percent spray solution, a vehicle speed of 10 m. p. h. would give a dosage of about 0.1 pound of toxicant per acre, or 1 quart of solution while covering a front of 72 feet. If the effective swath width is less than 600 feet, either the vehicular speed can be increased or the concentration of the spray reduced proportionately to give the same dosage. They can also be altered to give higher or lower dosages as desired.

Many hydraulic power sprayers are available for spraying orchards, trees, and field crops. They have a wide range of weight and capacity, and many of them are adaptable to mosquito control. Some of the county or district control organizations prefer to use pressures up to 700 or 800 p. s. i. to produce finer mists and to carry the spray farther out.

Power pneumatic sprayers.—Pneumatic power sprayers, in which the pressure for discharging the liquid is developed by means of an air compressor, are also available. A lightweight pneumatic sprayer, designed at the Orlando laboratory by C. N. Husman, has some special

advantages and is adaptable to various mosquito- and other insect-control problems. It was originally designed for installation in a jeep or other motor vehicle, with the power for operating a small air compressor derived from the generator shaft (fig. 6). Another model mounted on a two-wheel cart is operated by a small gasoline motor (fig. 7).

FIGURE 6.—Jeep equipped with a Husman pneumatic sprayer; operator pointing to location of air compressor.

FIGURE 7.—Husman sprayer mounted on a cart.

In both models a vane-type air compressor weighing about 36 pounds is used. This has a rated capacity of 8.3 cubic feet per minute at 20 p. s. i. A rubber hose extends from the compressor to a 5-gallon army auxiliary gasoline can, which serves as an insecticide supply tank. This tank is fitted with a hose connection, a standpipe extending to the bottom, two threaded sleeves welded into the top for attachments of liquid- and air-pressure gages, and a bypass regulating valve. Two pieces of ⅜-inch oil-resistant rubber hose, one for liquid and the other for air, connect the tank to the spray boom.

The spray head consists of a cluster of six air-mix nozzles attached to ¼-inch copper tubing (fig. 7). For a fine mist, Spraying Systems unit No. 40010:120–6–35–60 is used. Larger droplets or a greater range in droplet size can be obtained by replacing three or more of these nozzles with nozzle unit No. 60100:140–6–5270. For residual applications the coarser nozzles may be used or the spraying head can be removed and replaced by a fan-type pneumatic spray nozzle. With six of the finer nozzles the respective liquid flow rates with tank pressures of 5, 10, and 15 pounds are approximately 8, 14, and 30 gallons per hour. With six of the No. 60100:140–6–5270 nozzles the rates are 10, 27, and 39 gallons per hour. A pressure of 15 p. s. i. is the maximum recommended in the 5-gallon auxiliary gasoline can. The air line pressure is kept constant at 20 p. s. i.

The unit as installed in a jeep weighs about 50 pounds. The portable unit, including platform, wheels, and 2½-hp. motor, weighs about 135 pounds. The average droplet size obtained with this machine is appreciably smaller than with hydraulic sprayers, and a large proportion of the droplets are in the accepted aerosol range (less than 50 microns in diameter).

FIGURE 8.—One type of mist blower used experimentally by Army engineers.

Mist blowers.—Several types of mist blowers have been developed especially for the control of flying insects. In one type the liquid is pumped to the spray head at low pressure, where it is delivered into the center of a high-speed air blast (fig. 8). Some mosquito-control organizations prefer mist blowers over fog machines or high-pressure hydraulic sprayers for treating residential sections for adult mosquitoes. Emulsions are frequently used instead of oil solutions to avoid injury to vegetation. The output is greater than that of fog machines, and the residue left on the vegetation may destroy mosquitoes that move into the area after the spraying. Sprays containing 1 to 5 percent of DDT are usually employed. This type of machine may be used also for larvicide applications, especially where the breeding places are fairly wide and are best covered by a wind-drifted spray.

In another type of mist blower, called a Microsol machine (fig. 9), the spray is finely atomized by means of rotating or spinning disks

FIGURE 9.—Microsol machine mounted in a jeep.

and then dispersed by an air blast. This machine is sometimes called a mechanical aerosol generator, but the average droplet sizes fall more nearly into the category of a mist, i. e., greater than 50 microns in diameter. A small portable electric model (fig. 10) for use inside buildings, however, is said to give a large proportion of droplets within the accepted aerosol range.

Thermal fog generators.—A thermal fog generator (fig. 11) has been developed especially for the area control of adult mosquitoes and other flying pests. Heat is employed to break up the liquid into fine droplets, which are borne across country or through woods as a dense fog. Several machines based on this principle are available. Some of them have a combustion chamber in which the air is heated by a

gasoline burner before it is mixed with the insecticide and forced through the nozzle, or the atomized solution is vaporized by a blast of hot air. Another model uses a small jet engine to produce a high-velocity blast of heated air into which the insecticide is introduced (fig. 12).

The heated exhaust gas from motor vehicles has also been utilized for the production of insecticide smoke (fig. 13). A venturi is inserted in the exhaust pipe, and the insecticide is introduced into this constricted throat, where it becomes heated and then broken up by the expansion of the gases after passing through the exhaust pipe.

The droplets in such smokes or fogs are very small and remain airborne much longer than in most types of spray. For this reason they are even more at the mercy of atmospheric conditions and may therefore show much more variable results. In moderate breezes the fog may be carried long distances, and in rising air currents it will rise immediately above the lower strata where the insects are resting

Figure 10.—Portable Microsol machine.

Figure 11.—Thermal fog generator mounted in a jeep.

or flying. On the other hand, with a light breeze in a favorable direction and with air movements toward the ground, which occur when the temperature of the ground is lower than that of the air (inversion conditions), fog drifting slowly through woods or dense vegetation may be highly effective.

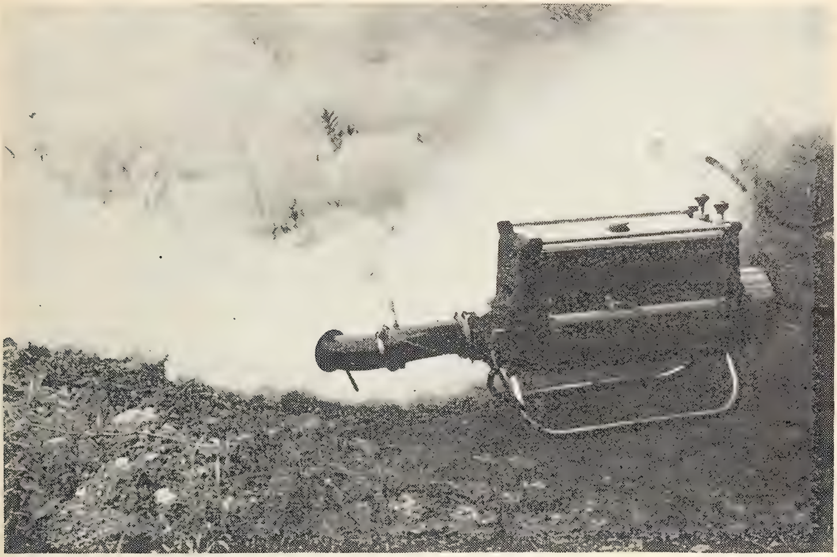

FIGURE 12.—Jet-type fog machine in operation.

FIGURE 13.—Motor-exhaust fog generator in operation.

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The solutions used in fog machines usually consist of 5 percent of DDT in fuel or diesel oil, or up to 10 percent in a mixture of fuel oil and an aromatic petroleum fraction (such as Velsicol AR–50 and S/V Sovacide 544–B), or other auxiliary solvent. In experimental work in Alaska with Tifa and Dyna-Fog generators and a modified jeep exhaust generator, the 20-percent DDT airplane spray caused excessive carbonization. When the 20-percent solution was reduced to 10 percent with fuel oil, it worked satisfactorily and produced a dense fog. The output of Tifa and Dyna-Fog generators ranges from about 20 to 40 gallons per hour. The Tifa has been reported to disperse as much as 60 gallons per hour.

The exhaust generator used in Alaska had an output of only about 4 gallons per hour, which was too low to give the desired dosage at a reasonable speed. A model developed in California was reported to give 10 gallons per hour when a ¾-inch venturi was employed. Even at this rate and with a 10-percent solution, the vehicle speed must be held to 2 m. p. h. to give an output of 5 gallons per mile, which is equivalent to about 0.055 pound of DDT per acre assuming a swath width of 600 feet.

The use of exhaust generators may damage motors from the back pressure created by the constriction in the venturi and from operation of the vehicle in low gear at high speeds to give effective discharge rates.

Outdoor Residual Treatments

Most species of mosquitoes rest outdoors in vegetation and may or may not enter buildings for blood meals. Experiments were carried out to determine the effect on the mosquito population of residual applications of DDT sprays to low vegetation and ground litter.

In early tests against *Aedes taeniorhynchus* in heavy vegetation 3 to 5 gallons per acre of an oil or emulsion spray containing 5 percent of DDT greatly reduced the population for several weeks. During the first 2 weeks the reduction ranged from about 80 to over 95 percent.

In later tests DDT, chlordane, BHC, and dieldrin were compared in residual sprays on 2-acre plots surrounding small isolated dwellings in coastal areas. The insecticides were applied with a small power sprayer at the rate of 50 gallons of emulsion containing from ½ to 2 pounds of active ingredient per acre. Lindane and BHC containing 40 percent of gamma were the most effective materials, both causing a great reduction for 17 days at all dosages. Dieldrin was effective for 13 days at the 2-pound dosage but for only 3 to 7 days at the lower dosages. With DDT and chlordane the reduction dropped below 90 percent after the third day at the highest dosage. Resistance may have been a factor in the short residual protection obtained with DDT. In the Northwest against snow-water species such treatments provided excellent daylight protection for 3 to 4 weeks. The reduction of mosquito annoyance about the houses by such residual treatments was marked during the daytime but much less so at night.

This method of protecting campsites and bivouac areas should prove practicable in certain situations, and the treatments can be repeated as often as required. In heavy vegetation single applica-

tions may be relatively long lasting. Supplemental pyrethrum or allethrin space sprays may be necessary to provide protection at dusk or night. When mosquitoes are migrating, the use of these fast-acting insecticides is necessary for effective control. DDT space sprays are not satisfactory under such conditions.

Control of Adult Mosquitoes Indoors

Liquefied-gas aerosols.—The pyrethrum-DDT aerosols now used extensively by civilians and the military services are modifications of the aerosol bomb first developed by members of the Bureau of Entomology and Plant Quarantine (see pp. 16–17).

A low-pressure aerosol adopted by the military (No. 2, table 3) is put up in 12-ounce dispensers. The directions for using this dispenser state that 7 seconds of spraying is ample for each 1,000 cubic feet of space. A valve delivery rate of 0.65 to 1.25 grams per second at 80° F. is specified. For its use outdoors see page 33. Repeated aerosol treatments in a room provide some deposit on the walls and floors, but coarse sprays are much better for residual treatments.

Liquefied-gas aerosols in 5- or 10-pound containers may be used in automatic dispensing systems in airplanes, messhalls, and warehouses. Solenoid valves at each of the outlets are activated as required from a central electric switch. Automatic timing devices may also be used for throwing the switch.

Besides DDT and pyrethrum, other insecticides, especially lindane, are being studied as to their use in aerosols.

Space sprays.—Household sprays containing 5 percent of DDT in deodorized kerosene are still widely used in hand spray guns for killing mosquitoes and other household pests. The 5-percent DDT spray (No. 23) is intended primarily for residual treatments. The space sprays (No. 26) contain 1 percent of DDT, 0.1 percent of pyrethrins or 0.16 percent of allethrin, and 0.8 percent of piperonyl butoxide. Other space sprays (No. 27) contain 1.5 percent of DDT and 2.5 percent of Lethane (type L) or 1.25 percent of Thanite (type T).

Lindane is coming into some use as an indoor space spray. The concentration used is 0.1 percent. Chlordane is not at present recommended for indoor space spraying.

For use in messhalls, warehouses, and other large spaces, electric and small gasoline-powered sprayers are available. The cart-mounted pneumatic sprayer developed at the Orlando laboratory and used for outdoor spraying also proved highly effective against stored-product insects in large warehouses. Several types of small pneumatic electric sprayers and a portable electric Microsol machine (fig. 10) for indoor use are available.

Residual sprays.—The long-lasting properties of DDT when applied to walls and other surfaces made possible the development of the residual method of insect control. This method has become of inestimable value in malaria control throughout the world and is used in areas where malaria control had not been possible because of high costs or adverse physical conditions that precluded the use of such methods as drainage or larvicide applications.

The standard practice in many malarious areas is to spray the in-

side walls of barracks and other living quarters with DDT solution, emulsion, or suspension at the rate of 200 mg. of DDT per square foot. The recommended application is 1 gallon of a 5-percent solution or emulsion per 1,000 square feet of surface. When suspensions are used, a concentration of 3.75 percent of DDT from a 75-percent wettable powder is advocated to reduce clogging of the nozzle. To give the 200-mg. deposit the amount of spray per 1,000 square feet is then increased to 1⅓ gallons, or the amount of wall surface per gallon is reduced to 750 square feet. A single application per season is sometimes sufficient, but re-treatment after 2 or 3 months may be required where walls are porous or dusty and under other adverse conditions.

Emulsions, oil solutions, or suspensions may be used for residual sprays. Suspensions are usually more effective, especially on porous surfaces, but they leave a visible residue, which is objectionable on finished surfaces. For use on painted or papered walls, solutions in refined kerosene are preferred to either emulsions or suspensions.

Chlordane and lindane are also effective in residual sprays against mosquitoes. Both materials show considerable vapor toxicity, but they are not nearly so long lasting as DDT. Dieldrin is also highly effective when applied in this manner and is longer lasting than either chlordane or BHC. However, it has not yet been fully evaluated for control of adult malaria mosquitoes. In the specifications covering emulsifiable concentrates of these materials (Nos. 7, 9, and 10) the recommended concentrations in the emulsions for use in indoor residual sprays are chlordane 2 percent, lindane 1 percent, and dieldrin 0.5 percent. When they are applied at the rate of 1⅓ gallons to 1,000 square feet of wall surface, the respective dosages are 100, 50, and 25 mg. per square foot. Because of their vapor toxicity these insecticides are not approved for complete coverage of walls in buildings, but may be used for spot treatment of infested areas.

Residual sprays may be applied with the standard pressure cylinder or power sprayers (fig. 14). The choice will depend on the size and number of buildings to be treated, their accessibility, and the means of transporting the equipment. A fan-type nozzle is preferable, but a cone-type nozzle giving a coarse wet spray may be used. A finely atomized spray is not efficient for this purpose. The spray nozzle should be held 12 to 18 inches from the surface and moved up and down or back and forth to cover the wall in successive strips.

AIRPLANE APPLICATIONS

Airplanes were first employed experimentally in 1923 by members of the then Bureau of Entomology for the control of malaria mosquito larvae in large swamp areas with paris green dusts. They were later used by the Tennessee Valley Authority and other agencies. The development of DDT greatly stimulated interest in the use of airplanes as a means of controlling culicine as well as anopheline mosquitoes. Workers at the Orlando laboratory demonstrated for the first time that adult mosquitoes could be controlled economically and effectively over large areas by aerial sprays. The high toxicity of DDT to both larvae and adults made it possible to treat large areas with few loadings of the plane, and thus keep costs low.

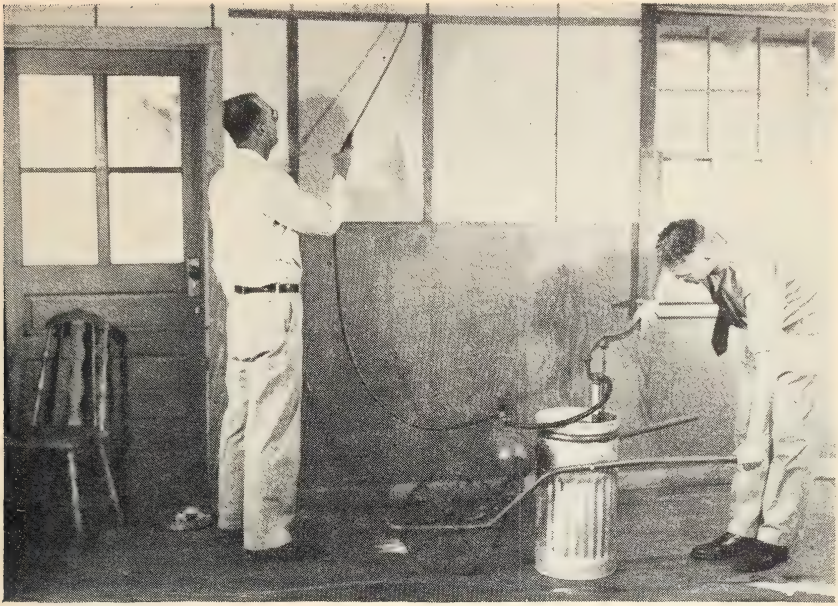

FIGURE 14.—Applying a residual spray with a wheelbarrow sprayer.

Dispersal Equipment

Sprayers.—The first airplane spray equipment developed and tested with DDT solutions was designed for use on an L–4 (Piper Cub) airplane. In this model, known as the Husman-Longcoy spray unit, the insecticide was dispersed through six nozzles mounted on the trailing edge of a venturi suspended beneath the fuselage. Soon afterward an underwing spray boom was developed and used both on monoplanes of the L–4 type and on biplanes of the PT–17 (N2S Stearman) type (fig. 15). Openings of a suitable size for dispersal

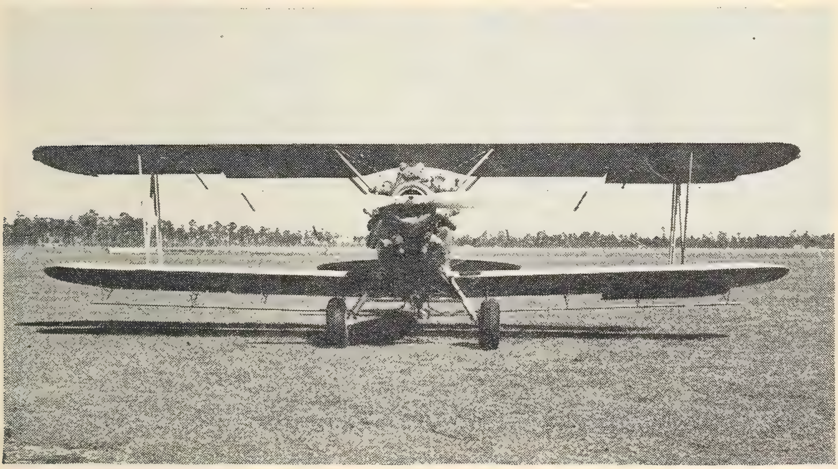

FIGURE 15.—A PT–17 plane equipped with underwing spray booms.

of the spray were drilled in the boom, and a breaker bar with a slightly beveled face was mounted behind the boom to increase the breakup of the spray droplets as they emerged from the drilled openings. Spray nozzles were also used on the spray booms instead of the drilled openings and breaker-bar device.

After the war large numbers of surplus training planes, principally PT–17's, became available, and most of the civilian mosquito-control work has been done with planes of this type. A tank of 75 to 90 gallons' capacity was installed in the front cockpit, and the insecticide solution fed to the spray booms under pressure furnished by a wind-driven pump mounted on a landing-gear strut or suspended beneath the fuselage back of the landing-gear assembly. Either a gear pump with pressures up to 100 p. s. i. or a centrifugal pump with pressures of 25 to 30 p. s. i. is used. The centrifugal pump permits the use of suspensions as well as solutions. Tanks of 80-gallon capacity have been approved for planes with 225-hp. engines and tanks of 200-gallon capacity for planes with 450-hp. engines equipped with motor-driven pumps.

This type of equipment, which can be installed without structural alteration to the plane, has been used on military planes of various models. Equipment installed in a C–47 plane for use in Alaska consisted of two wing booms each 18 feet long and a center boom 8½ feet long, two 375-gallon tanks mounted in the front of the cargo compartment, five 24-volt fuel-transfer pumps each with a capacity of 850 gallons per hour at a pressure of 14 p. s. i., and a switch box with a control for each boom mounted on the rear wall of the pilot compartment for operation by the copilot.

Spray-outlet holes of 0.064-inch diameter were spaced 2½ inches apart on the rear face of each boom, a total of about 80 on each 18-foot section. With two pumps in operation, the delivery rate of 20-percent DDT airplane spray was 28.3 gallons per minute, thus giving a coverage of 226 acres per minute at an air speed of 140 m. p. h. and allowing for a swath width of 800 feet. This gave a dosage of about 1 pint of solution containing 0.2 pound of DDT per acre. For this output the center section boom was not needed. The droplets, as estimated in the calibration tests, had a mass median diameter of 136 microns, with 77 percent having a diameter of less than 100 microns. The equipment later adopted for the C–47 by the Special Aerial Spray Flight of the Tactical Air Command consisted of full-length wing booms equipped with nozzles and a centrifugal pump operated by a 1½-hp. gasoline motor and developing pressures of about 25 p. s. i.

A C–47 plane with two underwing booms about 17 feet long with 12 nozzles (Spraying Systems No. 1/8 B–10) on each was employed in tests at Beltsville, Md., by members of the Division of Forest Insect Investigations of the former Bureau of Entomology and Plant Quarantine. With the 20-percent airplane spray solution and a pump pressure of 20–21 p. s. i. the discharge rate was 37 gallons per minute. The flights were made into the wind at an elevation of about 90 feet and with ground wind speeds varying from less than 1 to 6.2 m. p. h. As estimated from the droplets recovered on dyed cards in six tests, the average swath width over which the deposit was at least 0.05 gallon per acre was only 475 feet and the maximum about

600 feet, and for a deposit of 0.1 gallon per acre, 342 feet. The mass median diameter of the droplets was estimated to be 100 to 165 microns, with 75 percent of them less than 226 microns in diameter.

One of the simplest installations that has been used in cargo planes and medium bombers consists of a straight discharge pipe that extends about 3 feet below the belly of the fuselage (fig. 16). The pipes vary from about ¾ to 3 inches in diameter, depending on the desired output, and may be enclosed in a streamlined fairing. The lower ends of the pipe and fairing are cut at an angle of about 45°, to increase the atomization of the liquid. The insecticide is discharged by gravity from the storage tanks in the cargo compartment. The installation between the storage tanks and outlet pipe of a smaller tank with a float valve to maintain a constant head provides an even flow of the liquid. However, the pressurized boom-type equipment is much superior from the standpoint of atomization and effective swath width.

In another modification of the equipment for use with the PT–17, a 75-gallon auxiliary fuel tank suspended from a bomb shackle beneath the fuselage served as the insecticide container (fig. 17). This equipment was employed for experimental work at Orlando and also to a limited extent in civilian mosquito-control operations. The tank could be quickly attached or detached, and the two cockpits left free for normal use. A wind-driven gear pump was mounted on one of the landing-gear struts, or a centrifugal pump and propeller on a special bracket on the front end of the tank, the latter for use with suspensions

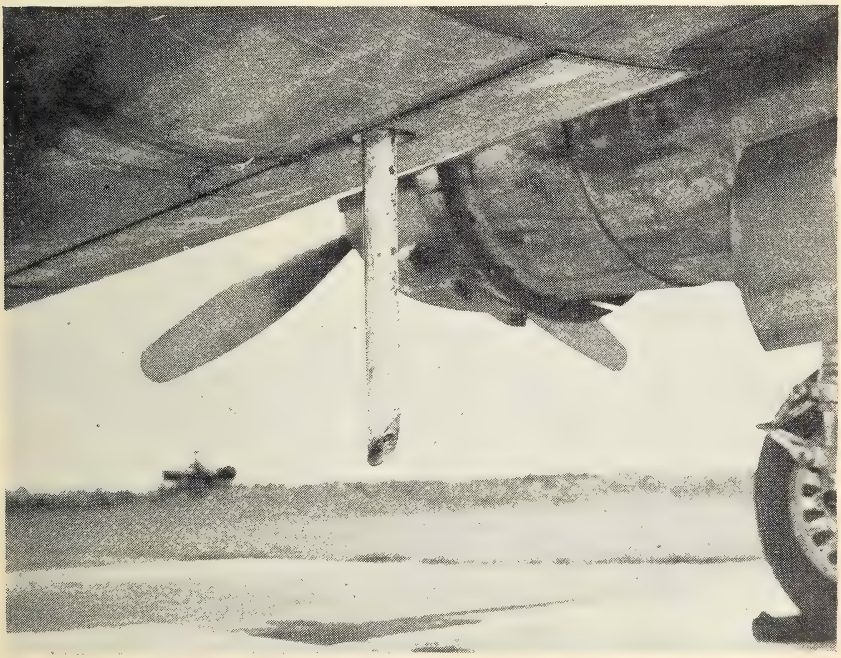

Figure 16.—A streamlined straight discharge pipe attached under the bomb bay of a B–25 plane.

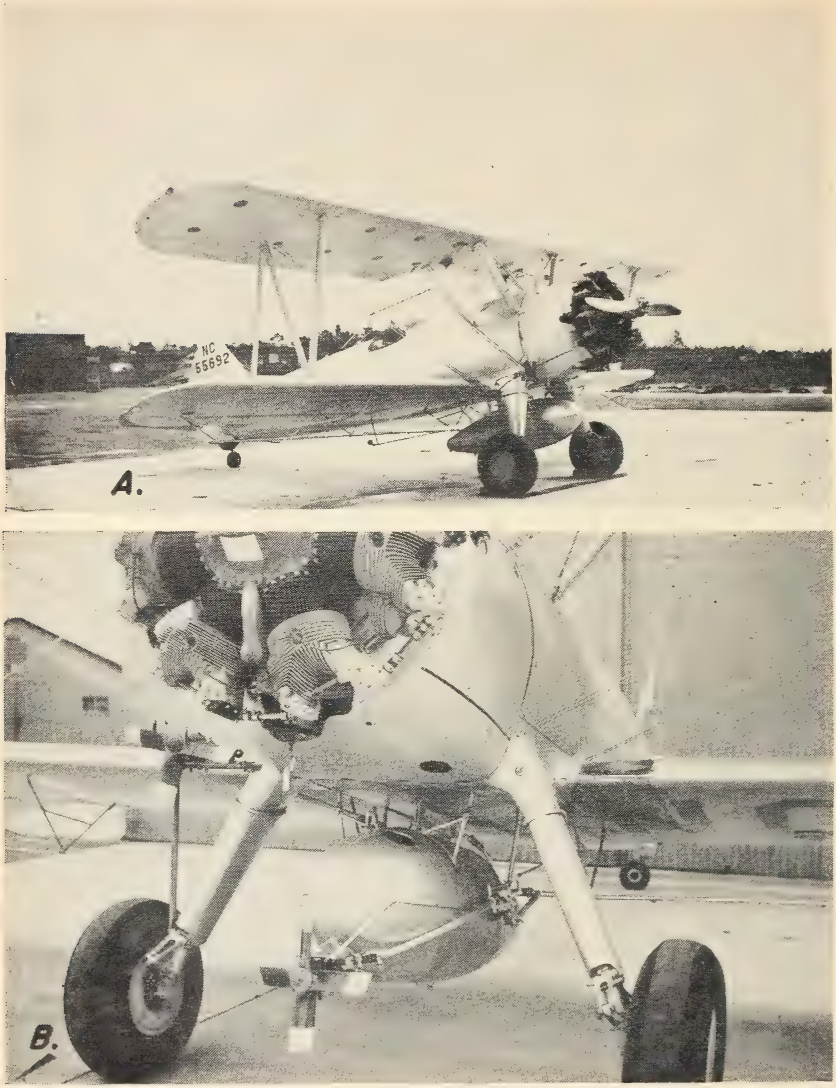

FIGURE 17.—A PT–17 plane with belly tank installed: *A*, Wind-driven gear pump mounted on landing-gear strut; *B*, wind-driven rotary pump mounted in front of tank for use with suspensions.

as well as solutions. Feed lines were connected to spray booms, and valves for opening and closing the feed lines and a brake for the wind propeller were controlled from the cockpit.

With the F6F type of plane used by the U. S. Navy, two 150-gallon auxiliary fuel tanks suspended on bomb shackles under the wings have been employed as spray tanks. Each is equipped with a straight outlet pipe discharging into a venturi suspended beneath the tank.

A kit developed for use on L–19 aircraft consists of two Chemical Warfare M–10 smoke tanks, modified with a venturi discharge system, which can be attached under the wings by the standard bomb-shackle mount.

Exhaust generators.—The possibility of utilizing the exhaust of a plane for atomizing and dispersing DDT was first investigated at the Orlando laboratory in 1943. A dense smoke (fig. 18) was produced when DDT solutions were injected into an extension of the plane's exhaust pipe, and this method gave promising results against both larvae and adults of mosquitoes. Later a venturi within the exhaust pipe (fig. 19), which improved the performance, was developed by the

FIGURE 18.—A C–47 plane with exhaust fog generator in operation.

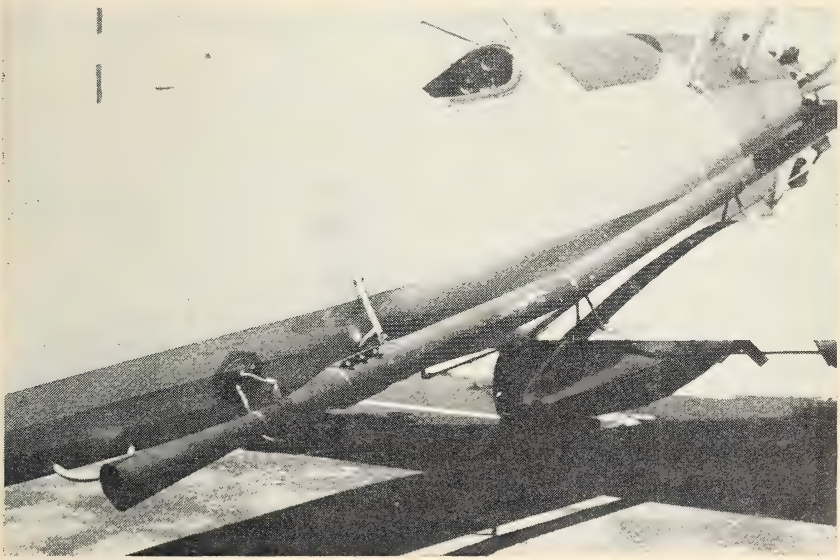

FIGURE 19.—Exhaust generator venturi installed at end of exhaust pipe of a PT–17 plane.

Tennessee Valley Authority (TVA), and the method was employed for several years for control of anopheline larvae on the extensive reservoir system along the Tennessee River. Against these surface-feeding larvae the exhaust-generated aerosols were effective at very low dosages. The visibility of the heavy smoke-fog was also of aid to the pilot in covering an area. The droplets were so fine, however, that only a small portion of the solution, averaging 10 percent or less, reached the water, the rest drifting away from the target areas. Subsequently the spray-boom type of equipment was adopted by TVA in place of the exhaust generator, as it caused more of the spray to reach the mosquito-breeding areas.

Helicopters.—Considerable experimental work has been done with helicopters for aerial dispersal of insecticides. Either boom-type equipment (fig. 20), thermal smoke generators (fig. 21), or dust hoppers are used. In general performance they compare favorably with fixed-wing airplanes and are superior against some kinds of insects, at least in certain situations. The advantages of helicopters lie in their great maneuverability, variable speed, strong downdraft at low speeds, and ability to land or take off in a small space. These characteristics make it possible to treat pockets and other difficult areas inaccessible to conventional aircraft, as well as to base operations close to the treatment areas independently of prepared landing strips, and thus reduce the amount of nonspraying time. The most important disadvantages are their high initial and maintenance cost, low cruising speed, small pay load, and the small number of experienced pilots available.

FIGURE 20.—Helicopter equipped with spray booms.

Figure 21.—Helicopter with thermal smoke generator in operation.

Spray Materials

Solutions.—A 5-percent solution of DDT in fuel or diesel oil has been employed most commonly in aerial spraying with small planes. The output of the equipment is adjusted to give a dosage of 2 quarts (approximately 0.2 pound of DDT) per acre, and either the quantity or concentration can be varied to give different dosages. Droplet size and evaporation of solvent can be reduced by the addition of 10 to 20 percent of motor oil. The addition of 1 percent of a spreading agent, such as Triton B–1956 (phthalic glycerol alkyd resin), is said to be of some advantage in larvicidal work. The 5-percent solution may be prepared by dissolving technical DDT in the oil or by diluting the 20-percent airplane spray with fuel oil. In larger and faster planes the 20-percent spray is used full strength, and the delivery rate and swath width are adjusted to give 1 pint per acre for the standard dosage. The 20-percent solution is sometimes used to advantage in small planes.

Emulsions.—Emulsions are employed for control of both larvae and adults, preferably in the smaller planes and under conditions that permit low-altitude flying in order to reduce evaporation before the material reaches the ground. A concentrate containing an aromatic hydrocarbon as the solvent and having a minimum flash point of 140° F. (see No. 8) is recommended, since the explosion hazard is slight and this type of solvent prevents complete evaporation while drifting in the air. This concentrate may be used full strength or with only slight dilution with oil when the regular 20-percent airplane spray is not available.

Suspensions.—Suspensions of wettable powders may be dispersed from airplanes, but their use is limited to larvicidal work. Adequate agitation in the tank must be provided to prevent settling. Either a centrifugal pump or a straight discharge pipe should be employed, as gear or rotary pumps are not suitable because of the abrasive action of the solid particles.

Pellets and granules.—Where the area to be treated is protected by trees and shrubs, some of the spray or dust is lost by sticking on the vegetation. Dusts penetrate vegetation better than sprays, but in dense growths it may even be impossible to get an effective quantity to the ground. In an effort to overcome this difficulty in reaching breeding places of mosquitoes and salt-marsh sand flies, pellets or granules impregnated with insecticides, which are heavy enough to penetrate thick growths, have been developed. This type of preparation is also being used in the control of soil-inhabiting insects. A granular form of bentonite clay of about $^{16}/_{30}$ mesh, called the quick-dispersant pellet form, was found promising for mosquito control when tested in ricefields by the Arkansas Agricultural Experiment Station and when tested in wooded or grassy salt-marsh areas in Florida by the Orlando laboratory. In Arkansas the pellets were impregnated with xylene solutions, whereas in Florida benzene solutions were used. Acetone was not suitable, as it sometimes caused the granules to swell and disintegrate. The solvent should evaporate to dryness so that the pellets will flow freely from the dust hopper.

Another advantage of a granulated insecticide is that it can be applied throughout the day at wind speeds much higher than is possible with ordinary sprays. Also, the residues will probably be greatly reduced on forage in livestock areas. On the other hand, the effective swath width is much narrower than for sprays, more flying time is required, and suitable equipment must be installed in the plane.

Dusts.—The paris green dust formerly used in anopheline control was applied at the rate of about 10 pounds of a 10-percent dust per acre. Thus a payload of 500 pounds was sufficient to treat only 50 acres. A similar load of 5-percent DDT solution applied at the rate of 2 quarts per acre would cover about 120 acres, or more than twice as much area. At 1 pint per acre of the 20-percent solution the same load would cover nearly 10 times that area. DDT dusts are effective at considerably lower dosages than paris green, but are limited to larvicidal treatment, whereas solutions are useful against adult mosquitoes as well. Moreover, a DDT dust is generally less effective against culicine larvae than a DDT spray. For these reasons dusts now are seldom employed except where planes equipped for crop dusting are the only ones available.

Factors Affecting Aerial Spraying

Altitude, wind velocity, and swath width.—The altitude at which spray missions are flown ranges from about 20 to 150 feet, depending on the nature of the terrain, the height of the vegetation, the size of the plane, the wind velocity, the droplet size, and the desired swath width. Wind velocities less than 5 or 6 m. p. h. are the most favorable, but

operations are still feasible at 10 to 12 m. p. h. if the spray is fairly coarse, a low altitude can be maintained, and the area to be treated is sufficiently wide so that a reasonable proportion of the drifting spray falls within it. Great care must be taken in judging the drift of the spray. At velocities above 12 m. p. h. operations are best postponed.

In large-scale spraying in Alaska with a C–47 equipped with underwing spray booms, the plane was flown at an altitude of 100 to 150 feet, the swath interval was 800 feet, and the output of 20-percent DDT spray was at the rate of either ½ or 1 pint per acre to give 0.1 or 0.2 pound of DDT. The speed of the plane was about 140 m. p. h. In other operations with the C–47 and other planes of equivalent size the swath width has ranged from 300 to 900 feet.

With smaller planes the swath width is usually set at 100 to 125 feet and the planes are flown at an altitude of 50 feet or less over open areas. Over wooded areas the planes must, of course, be kept high enough to clear the tallest trees. Planes applying thermal aerosols are flown at low elevation wherever possible (20 to 30 feet) to reduce loss of spray due to drifting.

Spray pattern and droplet size.—The delivery rate of the spray and the effective swath width at different elevations must be determined before control operations are undertaken. Information on the spray pattern and range of droplet sizes is also desirable. For this purpose samples of the spray are obtained on waved or stationary slides placed 10 to 20 feet apart in one or more lines at right angles to the line of flight. In one method glass microscope slides, 1 by 3 inches, are given a heavy deposit of zinc oxide smoke in which the falling droplets leave circular craters. The droplets per square inch or centimeter are then counted and the diameters of the craters measured under the microscope with an ocular micrometer. Another method commonly used is to treat the slides with a thin oleophobic coating, such as Dryfilm, on which the impinged droplets appear partially flattened. Measurements and counts are made under a microscope, or a portion of the slide is photographed and the measurements are then made from an enlarged projected image of the negative. To convert the measured diameters into actual droplet diameters the spread factor must be known. Since it varies with different solvents, the factor should be determined for each type of spray solution.

Slides waved at head height directly under the plane provide information on the entire droplet spectrum; the stationary slides show the range of droplet sizes and the numbers reaching the ground at increasing distances from the center of the line of flight. Both the proportion of droplets of different sizes or size groups and the mass median diameter are usually given. The latter is the size in microns of droplets at the midpoint of the cumulative volume index, obtained as follows: Multiply the cube of each diameter by the number of droplets of that size and divide the total of these products by 2 for the midpoint. The median diameter is also of some value but is considered less useful for comparison of the performance of different sprays and equipment.

Another centering constant, known as D_o, has been used by some investigators and gives more uniform mean measurements of spray

samples than the mass median diameter. It is based on the ratios of surface area to volume of the different-sized droplets. A rough approximation may be obtained with the equation

$$D_o = Sd^3n/Sd^2n$$

in which S indicates the summation of the diameters, d, cubed or squared, times the number of droplets, n, of that size. However, this simple equation is unduly affected by the presence of a few large droplets, and for the scattered measurements usually obtained in small sample counts the differential equation developed by Japanese workers and a graphic method of solution as suggested by American workers should be used (Kruse *et al. 11*). This method is simple to perform.

Effective swath width and dosage.—The effective swath width can be estimated roughly from the number of droplets per unit area, if the minimum number required to give an effective kill with the spray equipment and formulation employed is known. This information may be obtained by placing dishes of larvae at each slide station and observing the mortality at the end of 24 hours. The average droplet count at the farthest station showing mortalities of 90 to 95 percent is then taken as the minimum effective number.

The approximate volume of spray per unit area can also be estimated by determining from the diameter measurements the volume of the droplets recovered. The size of the samples that are measured, however, is limited, and the effect of evaporation of the solvent on the size of the droplets is difficult to estimate. Much more accurate estimation of volume or dosage is obtainable with an indicator dye or by chemical determination of the actual amount of DDT in samples collected on glass or metal plates. In the color method 0.5 to 1 percent of an oil-soluble dye, such as Du Pont oil red, is added to the spray solution, and samples are usually obtained on two plates from 6 to 12 inches square at each station. After the spray has settled, the plates are collected and the pairs placed together face to face for transport to the laboratory, where they are washed with a measured amount of acetone and a color reading is taken with a spectrophotometer. The readings are then compared with a standard curve for conversion to a quantitative basis. Because this dye fades rapidly in bright light, the plates must be collected and placed in a darkened container as soon as possible after the spray has fallen. Figure 22 is a typical graph of the spray deposit recovered at different distances from the line of flight.

Considerable attention has been given to the development of a more rapid method of estimating spray deposits in control operations, especially one that does not require the addition of a dye or other material to the spray solution itself. The use of white paper cards treated with the dye solution as tested by the Division of Forest Insect Investigations of the former U. S. Bureau of Entomology and Plant Quarantine and the Division of Forest Biology of the Canada Department of Agriculture appears to be a promising method (Davis and Elliott *5*, Brown *2*). Oil droplets falling on the cards make spots that can be counted and measured. If the spread factor for different-sized droplets on such cards has been determined, a rough

estimate of the amount of spray deposit can thus be obtained. The approximate quantity can also be estimated by comparing the cards with calibrated standard cards.

It is usually desirable, especially at low wind speeds, to apply the sprays at right angles to the wind direction, to give a wider and more even distribution. However, it is not always feasible to fly cross wind, or the wind direction may vary during the operation. For this reason the minimum effective swath width should be determined for flying into as well as cross wind.

After the swath width, dosage, and concentration of spray have been decided upon, the required flow rate (F) per gallon per minute for a known plane speed may be determined by the formula

$$F = SDW/495$$

in which S indicates the speed of the plane in miles per hour, D, the dosage in gallons per acre, and W, the swath width in feet.

This formula may be rearranged to give any one of the factors when the others are known. For example, the dosage for a known flow rate may be determined by $D = 495\ F/SW$. It is often more convenient to adjust the concentration of the spray to give the desired amount of DDT per acre rather than to change the flow rate.

Flight pattern.—The area to be treated should be studied both from detailed maps and from the air, and then the flight pattern and boundary markers should be selected and arrangements made for marking the swaths. The flight pattern should be planned to begin the runs on the downwind side to avoid flying into the drifting spray on subsequent runs. For short areas the pilot may make all the runs from one direction, circling completely around on the turns.

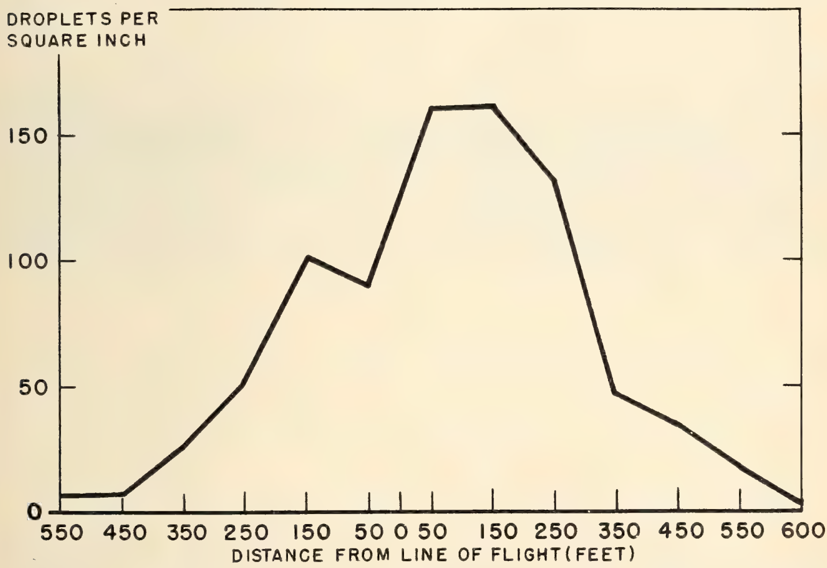

FIGURE 22.—Distribution of a spray deposit on the ground at different distances from the line of flight in tests with a C–47 plane equipped with underwing spray booms.

For large areas the consecutive flights are made in opposite directions with a tight bank and turn at each end, but if the area is both wide and long a double-strip pattern may be used to advantage. In this pattern the turn at the end of each run is more gradual, and the return run is made several swaths away from the first one or through the center of the plot. For an area requiring eight swaths, for example, the order of flying would be swaths 1, 5, 2, 6, 3, 7, 4, and 8, swaths 1 to 4 being flown in one direction and 5 to 8 in the opposite direction.

An experienced pilot can cover the small areas thoroughly without the use of swath markers, but for most flight operations marking of the swaths at some point is necessary to insure even coverage. Various types of markers have been used, such as cloth flags or cones on poles, weather balloons held by strings, and smoke grenades. Fluorescent cloth for flags is more visible under some conditions than ordinary white cloth. Weather balloons are satisfactory if a source of hydrogen or helium for inflating them is readily available. Smoke grenades

FIGURE 23.—Smoke grenade on a pole as marker for an airplane spray run.

(fig. 23) are probably the best, especially for large operations, except when the wind is so strong that the smoke is rapidly dispersed. Ordinarily the smoke is visible for several miles, and when used in woods the grenades can be raised on poles to get the smoke above the treetops. Another advantage is that they keep the pilot and ground crews informed of changes in the wind direction. Since the emission of smoke from a grenade is of short duration, careful timing must be used in starting them to insure a good cloud when the pilot is lining up his run. In covering large areas the plane is flown on a compass course lined up to fly over the marker, which is moved the proper interval by the ground crew after each run.

Radio communication from ground to air for instructions to the pilot is highly desirable, but if the proper equipment is not available prearranged code signals with flags should be established.

CONTROL OF FLIES

It was thought that DDT residual treatments, which had caused miraculous reductions or practical elimination of house flies around military installations, dumps, stables, and dairy barns, offered the final solution to the fly-control problem. However, resistance to DDT began to be noticeable after several years of intensive use. The degree of resistance has now become so high that DDT can no longer be used successively in a large part of the United States. Similar developments have been reported in other countries. Chlordane, BHC, and dieldrin were effective substitutes for a time, but tolerance to them developed rapidly, frequently in one season among flies already resistant to DDT. Resistance to closely related compounds also occurred. Fly populations soon showed a high tolerance to all chlorinated hydrocarbon insecticides.

Research was undertaken to find means of blocking or neutralizing the resistant factor and to find other classes of insecticides against which it is believed resistance is not readily developed. While awaiting information from these studies it has been necessary to return to older methods of control, such as space spraying with synergized pyrethrum, trapping, use of poisoned baits, and especially sanitation. However, residual and space sprays may still be effective in many areas, and the methods of using them for fly control are discussed briefly below.

RESIDUAL SPRAYS

For residual treatments on painted or papered walls in residences either emulsions or refined kerosene solutions are usually employed as they are less visible than suspensions. A 5-percent DDT emulsion or oil solution is applied at the rate of about 1 gallon per 1,000 square feet. This dosage gives approximately 200 mg. of DDT per square foot, or 2 grams per square meter. Wettable-powder suspensions are also used at slightly lower concentrations. The sprays are often applied to the point of runoff, and the amount required will depend on the nature of the surface. Some types of surfaces may need 1 gallon to 750 square feet. For this rate the 5-percent spray may be diluted to 3.75 percent to maintain the 200-mg. dosage. The amount of spray that surfaces hold before runoff begins also varies with the formulation used.

A wettable-powder suspension is preferred for use on porous surfaces, such as masonry, clay, or rough unpainted wood surfaces, as less of the DDT is absorbed in this form. However, the concentration of DDT that can be used satisfactorily without excessive clogging of spray equipment is about 2.5 percent in a suspension made with 50-percent or 3.75 percent in one made with a 75-percent wettable powder.

A hand-compression sprayer equipped with a nozzle producing a flat, fan-shaped spray is preferred for most indoor residual spraying.

For large, open rooms or buildings a power sprayer equipped with a suitable nozzle and operating at low pressure may be desirable.

In the field, latrines frequently become heavily infested with various kinds of flies. In addition to larvicidal measures (see pp. 58–59), residual sprays should be applied liberally to the inside and outside walls of the structures and the inside walls of the vaults.

Methoxychlor, a compound closely related to DDT, is also useful against nonresistant house flies. Although less effective than DDT, it is less toxic to mammals. Methoxychlor and lindane are the only chlorinated hydrocarbon insecticides now recommended for use in dairy barns or milk rooms. For fly control methoxychlor may be applied essentially as recommended for DDT.

Chlordane, BHC, and dieldrin are all more toxic than DDT or methoxychlor to house flies, but since they are more volatile their residual effect is of shorter duration. They may be used to advantage for the control of DDT-resistant flies and are recommended especially for treatments out of doors and in stables. Some of the organic phosphorus compounds, such as parathion and EPN, are highly toxic to flies, and there is some evidence, based on research by the Universities of California and Illinois, that they are less likely than the chlorinated hydrocarbons to produce resistance. Because they are more toxic to humans and domestic animals, they are not recommended for use indoors, but with proper precautions they have been used successfully around garbage dumps and other outdoor situations.

Chlordane is usually employed in a 2- or 2.5-percent kerosene solution or emulsion, applied at the rate of 1 gallon to 750 to 1,000 square feet to give approximately 100 mg. of chlordane per square foot. Lindane is employed in a solution, emulsion, or suspension at a concentration of 0.5 or 1.0 percent, applied at the rate of 1 gallon to 750 square feet to give a deposit of 25 or 50 mg. per square foot. Chlordane and lindane residual sprays are not recommended for complete residual coverage in living quarters. The use of technical BHC should be restricted to situations where the musty odor is not objectionable or there is no danger of contaminating foods.

Dieldrin is generally recommended for use at the rate of 25 mg. per square foot. This dosage is obtained by applying 1 gallon of a 0.5-percent solution, emulsion, or suspension per 750 square feet. Dieldrin should be used only by experienced operators and under the supervision of responsible officers who will make sure that there will be no hazard to people through food contamination or contact.

SPACE SPRAYS

Space sprays and aerosols containing DDT and allethrin, pyrethrum, or aliphatic thiocyanates are used for immediate control of fly infestations in living quarters, tents, or messrooms. The sprays are dispersed with hand sprayers, portable electric sprayers, or hand-compression sprayers equipped with fine-mist nozzles. The aerosols are dispersed by self-contained propellents from bombs.

Work was done at the Orlando laboratory on the development of fixed-spray and aerosol equipment for control of flies and other insects in buildings. One spray unit consisted of siphon-type nozzles attached to 1-quart containers, which were suspended below the ceiling

and suitably spaced to give thorough coverage of the room or building. The nozzles were operated at pressures of 2 to 5 p. s. i. through an air line connected with a compressor. In messhalls a small electric pump was used, and in dairies the necessary air pressure was obtained through the milking-machine pump by adjusting a valve in the cylinder head, which caused a changeover from vacuum to pressure in the air lines. These units were low in cost and simple to operate.

The fixed aerosol units consisted of solenoid-controlled dispensers, each with four outlets pointing in different directions, connected by ¼-inch copper tubing with a reservoir tank and an electric timer. Each unit delivered 0.8 gram of aerosol per second, and several units were suitably spaced on the ceiling to give the desired dosage. More mechanical difficulties, due chiefly to leakage and stoppage of the nozzles, were experienced with the aerosol than with the fixed-spray equipment. It was also more expensive to install and operate.

Most of the tests with these two types of equipment were carried out in open dairy barns, and the results were variable, chiefly because flies escaped as soon as the spraying was started. However, it is believed that such units would be highly effective in buildings that can be closed sufficiently to prevent escape of flies before they receive a lethal dose of the insecticide. For such locations the fixed spray would be preferred over the aerosol equipment.

Aerial spraying is seldom employed for the control of flies, but may be resorted to where they are abundant over a wide area and immediate control is desired. Such conditions may occur in combat areas as a result of unsanitary conditions and fly breeding in dead bodies. The dosages of different insecticides required for effective control by this method are not known, but for preliminary tests to determine the proper dosage the use of two to four times the amount used against mosquitoes is suggested. DDT, chlordane, lindane, and possibly dieldrin are insecticides of choice for mixed populations of house flies, blow flies, and others.

POISONED BAITS

For house fly control in areas where a high resistance to the residual sprays has developed, the use of poisoned baits has been very effective. Formerly a 1-percent solution of formaldehyde (2.5 to 3 percent of 40-percent formalin) or sodium salicylate in sweetened water or milk was employed to reduce fly infestations in the house. At this low concentration neither material is regarded as poisonous to humans or pets. During World War II a 1-percent solution of sodium arsenite in diluted molasses was found to make an effective poisoned fly bait when sprayed around fecal deposits, garbage, and dead bodies.

In more recent work at Orlando a 2-percent solution of sodium arsenate in equal parts of water and either blackstrap molasses or malt gave about 90 percent control of house flies in heavily infested dairy barns. Pans containing 2 liters of solution and covered with ¼-inch-mesh wire cloth were distributed about the barns (10 per barn), and the solution was replaced weekly. The use of such baits constitutes a hazard to man and animals and is not recommended at this time.

TEPP, malathion, Diazinon, and Bayer L 13/59 also were effective when used at concentrations of 0.05 and 0.1 percent in water con-

taining 3 to 10 percent of blackstrap molasses, sugar, or corn syrup. TEPP hydrolyzes rapidly in water and must be used fresh, but the other compounds will remain effective in water for several weeks or more. In these tests the baits were sprinkled on the floor of dairy barns at various locations where the flies congregated. An ordinary garden sprinkling can having about half the holes closed with solder to reduce the flow was used. Treatments made daily 5 days each week gave excellent control.

Malathion, Diazinon, Bayer L 13/59, and Chlorthion mixed with granulated sugar make highly effective dry baits. One percent of these insecticides is recommended, but good results have been obtained with concentrations as low as 0.25 percent. Wettable powders are preferred in making dry baits, but emulsifiable concentrates or the technical insecticide may be employed. A small amount of black or yellow food coloring should be added to dry sugar baits in order to minimize the possibility of their being mistaken for and used as regular sugar.

The dry bait is distributed from a shaker-top can or fruit jar with holes punched in the lid. Dry bait should be sprinkled thinly in strips on the floor or other places where flies congregate but where it will not contaminate animal feed, human food, or utensils. Usually about 1 ounce is needed for each 500 to 1,000 square feet, depending on the number of flies. Daily applications may be necessary to control flies under certain conditions, but after 2 or 3 weeks breeding may be reduced so that satisfactory control can be maintained with 2 to 4 applications per week.

Dry sugar bait is most effective on dry surfaces that are not very porous. On loose material such as straw the bait may fall beyond the reach of the flies, and on damp surfaces the sugar usually dissolves before the flies have a chance to eat it. In such cases the dry bait should be applied on feed sacks, sections of heavy paper, wood, or tin placed in locations where flies congregate.

An alternate bait for use on damp surfaces, especially outdoors, may be prepared with coarsely ground cornmeal. The meal is first coated with vegetable oil, 2 tablespoonfuls to 1 pound, and then are added 6 tablespoonfuls of a 25-percent malathion or Diazinon wettable powder and 4 tablespoonfuls of powdered sugar. If desired, 3 tablespoonfuls of lampblack may be added for coloring. The material should be thoroughly mixed with a paddle or mechanical stirrer. Cornmeal bait is applied in the same manner as dry sugar bait.

In view of the high toxicity of organic phosphorus insecticides to man, great care must be used in handling the concentrates. Because of the low concentrations in the bait and the method of application, they are not regarded as particularly hazardous if reasonable care is taken to avoid spillage on skin or clothing.

LARVICIDES

For military purposes fly larvicides are employed chiefly for control of larvae in latrines, garbage dumps, and other accumulations of waste. In combat areas the control of fly breeding in dead bodies is also imperative at times. Paradichlorobenzene, sodium arsenite, DDT, dieldrin, BHC, or lindane may be used as larvicides.

In deep-pit latrines that are tight and fairly dry, the fumes of paradichlorobenzene will not only destroy the larvae but prevent oviposition by repelling the adults. The granular material is applied at the rate of about 8 pounds per eight-seat latrine initially and 2 pounds twice a week thereafter. Sodium arsenite is used at a concentration of about 1 percent and is more effective than paradichlorobenzene in wet or shallow latrines. However, it is a deadly poison and should be used only with proper precautions and not at all if there is a possibility of contaminating ground water supplies or poisoning growing plants. If a sodium arsenite powder is available, it may be dissolved in water at the rate of about 1 pound to 10 gallons. A solution containing 54 percent of sodium arsenite is a stock item (No. 17) and is diluted 1 to 53 for treating latrines.

Oil solutions containing 5 percent of DDT or BHC are applied at the rate of 1 quart per seat per week. The treatments are more effective, especially in overloaded latrines, if they are divided into two or more applications per week. If a lindane emulsion is used, a concentration of 1 to 2.5 percent is suggested for preliminary tests to determine the minimum effective dosage and interval of treatment. A DDT-xylene emulsion was found to be more effective than a fuel oil solution, but it should not be used in enclosed spaces because of the danger of explosion when the xylene fumes are concentrated. However, the DDT nonexplosive emulsifiable concentrate, now a stock item (No. 8), may be used in latrines.

Residual sprays should be applied to the walls of the latrine and vault to reduce the number of adults that visit the latrine or emerge from the fecal medium in spite of the larvicides.

All these insecticides except paradichlorobenzene may be used for spraying fly-breeding places in the open, such as garbage dumps, manure piles, and other refuse, as well as dead bodies or animal carcasses that become infested before proper disposal can be made. Such bodies should be thoroughly sprayed on all sides as well as the ground underneath and for several feet around them. If sodium arsenite is used, a concentration of 2.5 percent is recommended. A 5-percent BHC emulsion with benzene as the solvent is also highly effective and rapid in action. The sprays will not destroy larvae inside the corpse or carcass, but the DDT and BHC residues should kill most of the adults feeding or ovipositing on the bodies and also those that emerge from escaping larvae.

CONTROL OF HUMAN LICE AND SCABIES

Three kinds of lice infest man—the body louse, the head louse, and the crab louse. They differ considerably in habits and therefore require different methods of control. Since the body louse is the vector of epidemic typhus and other diseases, emphasis has been placed on development of measures for its control. The head louse is closely related to the body louse and presumably may also transmit disease. The crab louse is not known to transmit any disease, but does cause much irritation of the skin. All three species are cosmopolitan in distribution.

Scabies, or human itch, is caused by the itch mite, which burrows through the outer layer of the skin. The disease is common, but its

incidence usually is not high in military personnel. It is prevalent in some foreign countries and is considered to be an important military problem.

At the Orlando laboratory an emulsifiable concentrate was developed for use in a spray or wash for controlling both lice and scabies. Research at this laboratory led to recommendations for louse control that were adopted by the military during World War II and were applied extensively under various field conditions. During the Korean war body lice that were highly resistant to DDT were encountered, and further research was required to develop a substitute insecticide.

The following control measures are those developed or investigated for the Armed Forces at Orlando, although other methods, such as methyl bromide fumigation and steam sterilization (No. 15, table 3; Nos. 2 and 3, table 4) of clothing, are also in use.

BODY LICE

The body louse spends its life in the clothing except for a short time on the skin while feeding. The eggs are laid on the cloth, attached to the fibers. Woolen cloth is much preferred to other kinds. In looking for infestations one should examine the clothing along the seams and folds, especially on the inside of the underwear. Because of the habits of this louse, control measures are directed largely toward the treatment of clothing.

Louse Powders

Three kinds of louse powders are carried as stock items or are under specification—10 percent of DDT in pyrophyllite (No. 5), 1 percent of lindane in pyrophyllite (No. 3), and MYL-type powder (No. 6), containing pyrethrins with or without allethrin, a pyrethrum synergist, and a louse ovicide.

The 10-percent DDT powder is the standard material issued for louse control. It is packaged in 2-ounce sifter-top cans for individual use and in 5- and 25-pound containers for mass use. With the sifter-top can the powder should be applied over the inner surface of the underwear (fig. 24), with special attention to the seams, and evenly distributed by hand. The seams inside the shirt and trousers should be treated in a similar manner. The socks should also be treated. About 1 ounce of powder is necessary for one treatment. If it is not feasible to remove the clothing, the powder may be shaken into the clothing through the openings in the shirt and trousers.

DDT is rather slow in action, but the lice are usually immobilized in less than 6 hours. It is not ovicidal, but owing to its long-lasting effect a single application can eradicate an infestation since the eggs normally hatch in less than 2 weeks.

Mass treatment has been employed with great success for the control of lice in large units of troops and prisoners of war and for control of epidemic typhus in civilian populations. A hand-operated plunger duster (fig. 25) and a gasoline-powered unit with 10 duster heads (fig. 26) are issue items (Nos. 6 and 7). The powder is blown between the underwear and the skin. It is blown down the neck of the shirt, up the sleeves, and into the loosened trousers from as many

directions as possible, front and back. In delousing women an extra quantity may be blown down the neck of the dress and application at the waistline omitted. About 1½ ounces per person is sufficient for winter dress. The hair, hat or cap, extra clothing, and bedding should be included. One such treatment with DDT is generally adequate to control infestations.

Powder containing 1 percent of lindane has been approved for military use in areas where DDT-resistant lice are encountered. This material was used successfully on a large scale in Korea after DDT powder became ineffective. Directions for its application are the same as for DDT powder. However, since it is not so long lasting, a second application within 7 to 10 days is advocated.

The MYL powder was developed before DDT became available. The original formula contained 0.2 percent of pyrethrins, 2 percent each of *N*-isobutylundecylenamide (synergist) and 2,4-dinitroanisole (ovicide), and 0.25 percent of Phenol S (antioxidant). Upon the discovery of DDT-resistant lice in Korea, further tests were made with this preparation and the formula was slightly changed by reducing the amount of Phenol S to 0.1 percent and substituting sulfoxide as the synergist. One type also contained 0.3 percent of allethrin in addition to the pyrethrins.

The MYL powder has a very rapid action on the lice. In tests at Orlando they were all immobilized within 15 minutes, and unable to take blood meals after 10 minutes. On cloth impregnated with DDT, a 2-percent solution or a 10-percent dust, lice continued to feed for 1 or 2 hours.

FIGURE 24.—GI applying DDT to underwear from a sifter-top can for louse control.

The residual action of the MYL powder was much shorter than that of DDT, but it did give complete control of lice for 1 week and a high degree for 3 or 4 days longer. Although this length of time took care of most of the nymphs that emerged from eggs present at the time of treatment, the inclusion of the ovicide was thought desirable. However, it was difficult to reach all the eggs with the powder, and for safety two treatments a week apart are recommended.

FIGURE 25.—Applying DDT to clothing with a plunger-type hand duster.

FIGURE 26.—Mass treatment of troops with a motor-driven duster for louse control. (Courtesy of Capt. R. M. Altman, U. S. Army.)

Impregnation of Garments

DDT is very effective and long lasting when used to impregnate clothing. If the clothing is treated in mass before issuance or during laundering, the method largely eliminates the personal factor and provides more permanent louse control than powders. Properly impregnated garments remain effective through 6 to 8 launderings. Troops provided with two suits of impregnated winter underwear should remain free of lice during an entire winter, the season when lice are most prevalent. In general, a dosage of DDT equivalent to about 2 percent of the dry weight of the garment is recommended. This dosage is 15 to 20 grams (0.5 to 0.7 ounce) for the regular issue, winter-weight, 50-percent-wool underwear.

Garments may be impregnated with DDT in a volatile solvent or in an emulsion. In the first method the underwear is dipped into a solution, such as a cleaning solvent containing the desired amount of DDT, the excess solution is removed by wringing, and the solvent is allowed to evaporate before the garments are worn. This method is especially useful where dry-cleaning equipment is available. In the second method a 25-percent DDT emulsifiable concentrate (containing xylene as the solvent) diluted with water to the desired concentration is used for wetting the garments. They may be dipped individually in a pan or helmet, or by batches in a larger container, such as a drum, or in laundry equipment. This

method is especially adaptable for use in portable or other laundry facilities (see pp. 79–80).

Before either method is used, the approximate amount of solution or emulsion retained in the garments after wringing or spinning should be determined. From 1 to 2 pints is required for a suit of winter-weight underwear. The concentration is then adjusted to give the desired amount of DDT per garment. If the volume is 2 pints, the recommended dosage would be attained with a 2-percent solution, containing approximately 18 grams, or 0.64 ounce.

Studies have shown that lindane is also effective as a clothing impregnant for louse control, although much less persistent than DDT. A set of winter-weight underwear impregnated with 2.5 to 3 grams of lindane in about 2 pints of a 0.3-percent solution or emulsion will give effective control of lice for a week or 10 days. Garments treated with this small amount of lindane are not effective after laundering and must therefore be re-treated. The Army Environmental Health Laboratory is investigating the toxicity of lindane to humans, but has not yet approved its use as a clothing impregnant for control of lice.

Sprays for Louse Control on the Body

A spray formula (No. 11) developed primarily as a treatment for head and crab lice and scabies is also issued for the control of body lice where it is desirable to eradicate all lice present on groups of personnel in a short period, as at a port of debarkation in the United States in connection with methyl bromide fumigation of the clothing of returning troops.

The formula is an emulsifiable concentrate known as NBIN and contains the following materials (all percents by weight): Benzyl benzoate 68, DDT 6, benzocaine 12, and Tween 80 (polyoxyalkylene derivative of sorbitan mono-oleate) 14. It is diluted with 5 volumes of water for application. The individuals are stripped, and while their clothing is being deloused by fumigation they are required to take a bath and are then sprayed with the NBIN emulsion with a power compressor and a paint-spray nozzle. The spray is applied to the pubic and anal regions, the armpits, and other hairy parts of the body to destroy body and crab lice, and to the head to destroy head lice. The spray should be kept out of the eyes by covering them with the fingers. Treated persons should not bathe again for at least 24 hours. Benzocaine is a very effective ovicide, so that the eggs as well as the active stages are killed. About 20 ml. of finished emulsion is required per individual, or about 5 gallons per 1,000 men.

HEAD AND CRAB LICE

Head and crab lice live continuously on the body, and their eggs (nits) are attached to hairs. Eggs of the head louse are found chiefly on the hairs of the head, and those of the crab louse chiefly on the hairs of the pubic region but also occasionally on other hairy parts of the body. The presence of either species can be readily determined by examining for nits.

The NBIN formula (see above) diluted 1 to 5 in water is highly effective against both species. It may be applied as a spray or for individual

treatments poured onto the hairy parts of the body and distributed with the fingers.

The DDT and MYL powders issued for the control of body lice are also effective against head and crab lice and are easily applied from the 2-ounce sifter cans. Either powder will usually eradicate an infestation if the hair is not washed within a week after treatment. To be certain of destroying all the nymphs that hatch from eggs, a second treatment after 7 to 10 days is suggested. For a heavy infestation the MYL powder is preferred, as it stops the activity of the lice very quickly. With DDT the lice become abnormally active and cause intense irritation of the skin. The MYL powder may be used if strains of DDT-resistant lice are encountered.

SCABIES

Research on scabies treatments was carried out at the Orlando laboratory in Florida and in cooperation with Army Medical and Sanitary Corps officers in other areas. Benzyl benzoate by itself has been used rather extensively for scabies control, but is more effective in the NBIN formula (see p. 64). Benzocaine was included primarily as an ovicide, but it is also a local anesthetic that relieves the itching caused by lice and the scabies mite.

The NBIN formula has practically no odor, and does not leave an undesirable residue on the body or irritate the skin. For treating a case of scabies, this formula is diluted 1 to 5 with water, as for lice, and applied as a spray or with a sponge. The entire body except the head should be treated, with particular attention to the areas where lesions are apparent. About 60 to 75 ml. of the dilute emulsion is ordinarily required for one treatment. The patient should be instructed not to bathe for 24 hours. One thorough treatment usually eliminates an infestation, but if a second treatment is required, it should be made about a week later.

CONTROL OF OTHER MEDICALLY IMPORTANT ARTHROPODS

BED BUGS

DDT was found to be highly effective against bed bugs. With its long residual action it seemed to provide the solution of a problem that has long been difficult to handle in army barracks, as well as under many conditions in civilian life. A 5-percent DDT spray applied to the beds (fig. 27) and into cracks and crevices in walls has eradicated these insects from infested buildings. Either a kerosene solution or an emulsion may be applied with a pressure sprayer or power equipment. The spray should be fairly coarse and wet in order to leave an effective residue.

In treating a bed it is important to cover completely the mattress, springs, and bedstead, directing the spray particularly to the corners and other places where the bugs hide. This requires about 100 ml. of spray. Cracks in the baseboards and walls, to a height of several feet, should also be treated. Although not all the bugs can be reached with the spray, the DDT residue will kill those that later crawl on the

treated surfaces. Reinfestation is not likely to occur for many months.

Although sprays are usually recommended for bed bug control, DDT dusts are also effective. Troops provided with DDT or MYL louse powder can obtain protection by applying it to the bed, mattress, and blankets. Owing to the slow action of DDT, complete protection from annoyance may not be experienced the first night. The MYL powder acts more quickly, although final results may not be as good as with DDT.

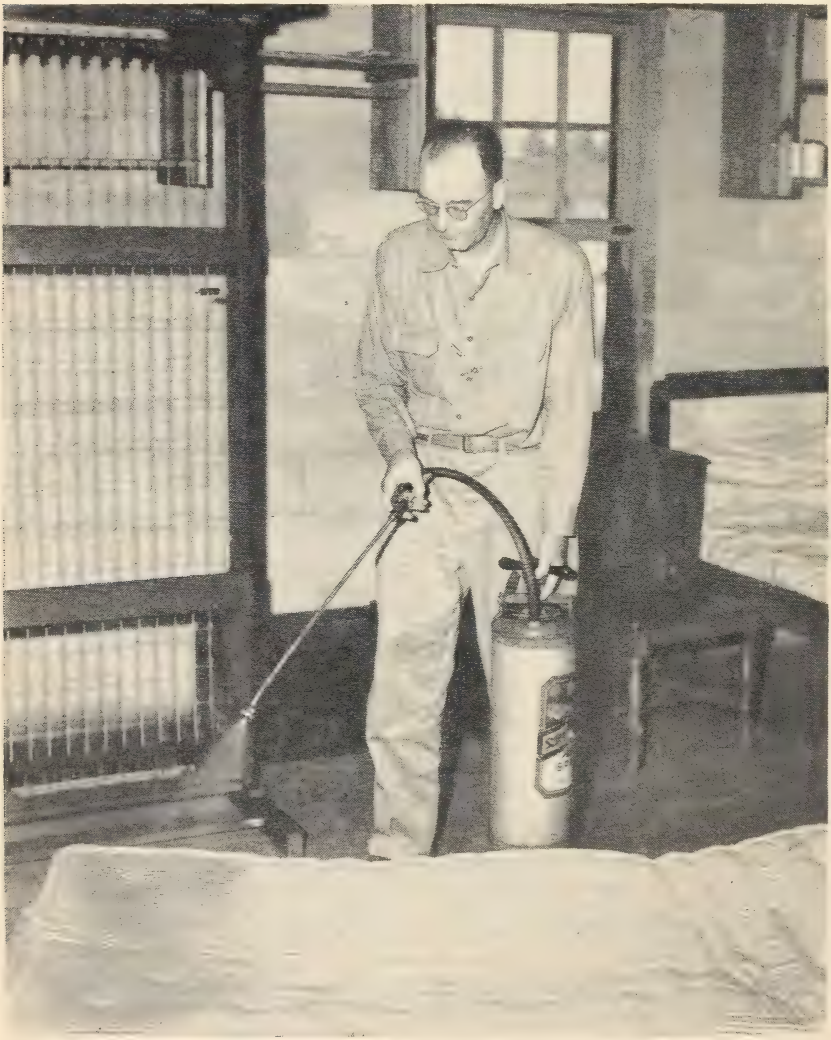

FIGURE 27.—Spraying a mattress for control of bed bugs.

DDT has been used with great success in crowded, low-rental sleeping quarters in the poorer sections of large cities. It is from such places that reports of DDT resistance in bed bugs have been received.

If DDT fails to control bed bugs, a synergized pyrethrum spray is recommended. The spray should contain 0.2 percent of pyrethrins and 1 percent of piperonyl butoxide, and should be used as a residual treatment as described for DDT. This spray is less persistent than DDT and a second treatment is suggested within 2 to 4 weeks. Sprays and dusts containing 1 percent of lindane have been employed effectively by commercial operators.

COCKROACHES

Chlordane is more toxic than DDT to cockroaches and is recommended for their control. It is usually applied in a 2-percent kerosene solution or emulsion with a pressure sprayer or power equipment, but a 5-percent dust may be used. In living quarters application should be limited to places where the roaches commonly crawl or hide, such as baseboards, corners, large cracks, pantry shelves, and behind furniture and kitchen sinks (fig. 28). As is true for all indoor spraying, special care must be taken to protect food and dishes from contamination. In pantries, cupboards, and the underside

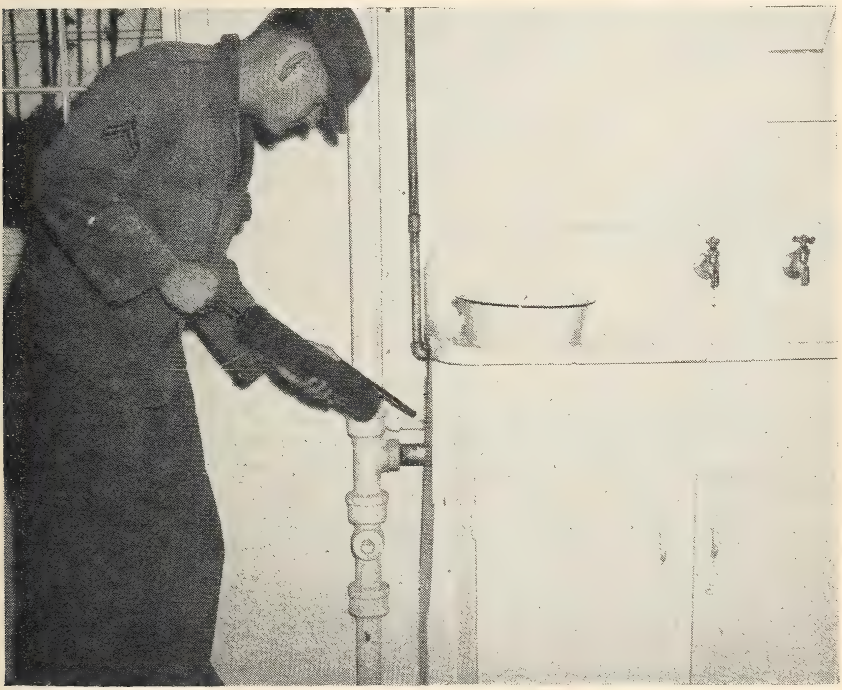

FIGURE 28.—Dusting for control of cockroaches.

of tables application of the material with a paintbrush instead of as a spray will avoid contamination of food, utensils, and other articles. A 2-percent chlordane spray is covered by a military specification (No. 22).

DDT in a 5-percent spray has also been used successfully in the control of cockroaches. It should be applied in the same way as a chlordane spray.

A 10-percent DDT or 5-percent chlordane dust may be blown into cracks and crevices and under and around stored articles or equipment. Dusts are recommended for treating telephonic or electrical equipment, fuse boxes, or around open flames. Combined spray and dust treatments are frequently used advantageously.

A spray containing 5 percent of DDT and 2 percent of chlordane is sometimes recommended for cockroach control on the theory that the combination has greater immediate and more prolonged effectiveness than one containing either insecticide alone. A military specification (No. 22) covers a spray of this type.

Strains of cockroaches highly resistant to chlordane and slightly resistant to DDT have been encountered. Lindane is one of the materials that may be used as a substitute. One-percent sprays or dusts should be applied in the same way as described for chlordane or DDT. Combinations of pyrethrum and the synergists piperonyl butoxide, sulfoxide, or propyl isome may also be used. A refined kerosene solution or an emulsion containing 0.2 percent of pyrethrins and 1 percent of the synergist should be applied thoroughly every 2 or 3 weeks to all places where the roaches hide or run until the infestation is under control.

Sodium fluoride powder is still employed at times for roach control. It is placed in cracks, corners, and around plumbing for the roaches to walk over. It must be kept dry to be effective and allowed to remain for 24 to 48 hours.

Sodium fluoride is a white powder resembling flour and is highly poisonous to humans. It is frequently combined with pyrethrum or a similar quick-acting material for rapid knockdown, and colored greenish gray as a safety precaution.

FLEAS

DDT sprays will control cat and dog fleas in or around buildings. A 5-percent solution or emulsion is sprayed on the floor and the lower foot or two of the walls at the rate of about 1 quart to 250 square feet. Earth floors or infested ground will require about twice as much spray.

DDT dust may also be used for flea control. Infested persons may be dusted with the 10-percent powder in the same manner as for body lice. Where one is frequently exposed to flea infestations, particularly in the presence of flea-borne plague or murine typhus, treatment of the clothing with a flea repellent is recommended (see p. 76).

For control of fleas on dogs a 10-percent DDT or a 1-percent lindane powder should be dusted into the hair along the back and neck. For cats, pyrethrum or derris powder rather than DDT or lindane should be employed as they are less hazardous to this animal.

Ten-percent DDT dust has been used successfully for destroying rat fleas in citywide campaigns conducted by Federal and State health agencies for the control of murine, or endemic, typhus. The dust is blown by hand or power duster into rat burrows, runways, and all accessible harborages, where it evidently is picked up by the rats in sufficient quantities to destroy the fleas on their bodies and in their nests. A foot pump such as is used for applying cyanide is one type of duster recommended for treating the burrows and a hand dust-sifter for treating the runways.

Household pyrethrum sprays with added synergists applied thoroughly to floors and lightly misted on furniture and other places where fleas may occur will also control infestations. Treatments may have to be repeated at intervals of several days.

In laboratory tests at Orlando heptachlor, dieldrin, aldrin, and lindane dusts were all more toxic than DDT to fleas. In Korea the human flea was prevalent in native houses with dirt floors. Lindane and dieldrin emulsions sprayed on the floors once a week were effective, particularly when rat baits containing warfarin were exposed concurrently. Chlordane was less effective than lindane or dieldrin but more effective than DDT. On grounds or in buildings not occupied by people, lindane, chlordane, or dieldrin may be used in sprays or dusts. A thorough treatment of the grounds with a large volume of spray may be necessary because of vegetation and debris. Two gallons of a spray containing 1 percent of DDT, 0.5 percent of chlordane, or 0.125 percent of lindane or dieldrin is suggested for each 1,000 square feet.

ANTS

Chlordane is especially toxic to ants. A 2-percent solution in kerosene is recommended for their control in buildings. It may be applied with either a paintbrush or sprayer to table legs, window sills, pantry shelves, and around sinks, drainboards, and water or drain pipes or other places where ants are seen crawling. Emulsions or wettable-powder sprays containing about 0.5 percent of chlordane are useful in treating ant mounds in lawns and fields.

The imported fire ant has become a serious pest in Alabama and Mississippi and seems to be spreading rapidly into adjoining States. A spray containing 0.37 percent of chlordane has been recommended for its control. About 3 gallons should be applied to an average-sized mound, or sufficient to saturate it and an area about 3 feet wide around it.

SAND FLIES

In the United States the name "sand fly" is applied to species of the genus *Culicoides* (family Ceratopogonidae) found along the Atlantic and gulf coasts. In other parts of the world the name is applied to species of the genus *Phlebotomus* (family Psychodidae, or moth flies). Except for their small size, the two genera are entirely dissimilar in habits and distribution, and the confusion of names is unfortunate. It is suggested that when used for *Culicoides* the name be qualified as salt-marsh or culicoid sand flies.

The *Culicoides* species, so far as known, all breed in moist soil, and most of them are found in fresh-water locations, principally in tree holes and along the banks of ponds and spring-fed streams. In

some places, especially in mountain meadows and along streams, they become very annoying. These fresh-water species are commonly called punkies, no-see-ums, or biting midges. Only a few species are found associated with salt marshes, but they become abundant and annoying in many coastal areas.

Aerial and ground sprays and fogs of various kinds have been used in controlling salt-marsh sand flies. However, such treatments may be effective for only a short time when the insects are migrating. Outdoor or indoor gatherings of people can be protected with wind-drifted DDT or lindane fogs or mist sprays dispersed as frequently as needed. Residual treatment of vegetation with DDT around living quarters, parks, and camping areas will provide some relief, although the insects may fly into the areas during migration and cause annoyance before contacting the treated surfaces.

Because of the small size of these flies, ordinary window screens or bed nets provide little protection against them. Relief can be obtained, however, by painting the window and door screens with a 5-percent DDT solution to which 10 to 20 percent of lubricating oil has been added. If the bed nets are sprayed, the heavy oil should be omitted. Residual spraying of bedroom walls has also been found useful.

The larvae of salt-marsh sand flies are found in very wet muck or sandy soil, usually on portions of the marsh affected by daily tides. Experimental work in Florida has shown that the larvae can be controlled with several of the new insecticides, of which dieldrin, heptachlor, BHC, and chlordane seemed the most promising. About 2 pounds of chlordane per acre, 1 pound of dieldrin, heptachlor, or sufficient BHC to give 1 pound of the gamma isomer gave control lasting for several months. However, since these heavy dosages may injure aquatic life, the treatments should be limited to places where the damage will not be serious.

Species of *Phlebotomus* are sufficiently numerous in some regions to be rated as pests, but they are of chief importance as vectors of pappataci fever, kala azar, and Oriental sore, which are widely distributed in southern Asia and the Mediterranean region, including North Africa, and of verruga peruana, which is found in high valleys among the mountains of South America. Several species are found in the United States, but they are not known to be of any economic importance.

Residual spraying of indoor and outdoor resting surfaces with DDT has been reported to give effective control of *Phlebotomus*. From experiments conducted in Peru, Hertig and Fairchild (*9*) reported that the treatment of stone walls, which constitute the principal outdoor shelters and breeding places, gave a marked reduction of sand flies. Combined with house spraying it reduced their numbers to a very low level, and the effect persisted after 12 to 19 months. Observations made by Dr. Hertig (*8*) concerning malaria-control programs in Greece and Sardinia indicated a marked reduction of sand flies as a result of DDT residual spraying.

BLACK FLIES

Blood-sucking flies of the family Simuliidae constitute a pest problem in many areas. In parts of Mexico, Central and South America,

and Africa a filarial disease, onchocerciasis, is known to be transmitted by these insects. In the United States the pest species include the southern buffalo gnat, plagues of which sometimes follow overflow of the lower Mississippi River. Other species are annoying in the Adirondacks and various other parts of the United States, western and northern Canada, and Alaska.

The adults can be killed with DDT sprays, but in Alaska they appeared less susceptible than mosquitoes to this means of control, and the reduction in numbers was of short duration owing to rapid reinfiltration into the sprayed area.

The larvae of black flies attached to rocks and vegetation in flowing streams have proved susceptible to control with small amounts of DDT applied to the streams in oil solutions, emulsions, or suspensions. TDE and some of the other new insecticides were also effective but usually less so than DDT.

In Alaska and northern Canada the effective dosages of DDT in experimental treatments from the ground ranged from 0.1 to 0.7 p. p. m. applied over a period of 15 minutes, or a dosage product (parts per million times minutes) of 1.5 to 10.5.

When control operations are planned, an initial dosage of 0.1 p. p. m. for 15 minutes at intervals of 1 mile or for about 4 minutes at intervals of ¼ mile along the infested streams is recommended. The dosage or interval can then be increased or decreased as the results indicate. The approximate volume of stream flow per second is estimated from measurements of the average velocity of the water and the cross-sectional area of the stream at the point of application. The larvicide may be applied with a hand sprayer or allowed to flow into the stream from a container adjusted to empty in the desired time (fig. 29).

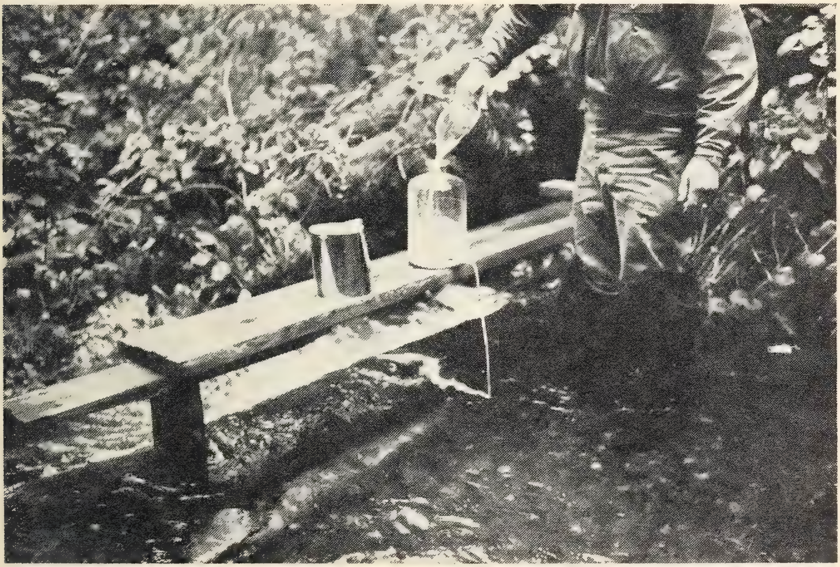

FIGURE 29.—Treating a stream with a DDT emulsion for the control of black flies.

If such measurements are difficult to obtain, the larvicide may be applied at 0.025 to 0.05 pound of DDT per acre of water surface. These amounts are contained in ½ to 1 pint of a 5-percent DDT solution or emulsion, and are applied to 32 feet of stream width if the treatment interval is ¼ mile or 8¼ feet for intervals of 1 mile. The application should be spread over a period of 5 to 15 minutes. With an average stream depth of 6.4 inches, a velocity of 2 m. p. h., and an application time of 10 minutes, these rates would apply 0.05 to 0.1 p. p. m. to the treated portion of the stream.

Although it is convenient to compute the dosage on the area of the treatment interval, actually the treatment is limited to a portion of the stream the area of which depends on the velocity of the water and the application time. In the example given above the amounts applied to the treated segment would be 0.073 to 0.146 pound per acre instead of 0.025 to 0.05 pound as computed. The larvicide becomes dispersed in the water by the turbulent action of the stream, and the dosage must be high enough to be effective during the time that the treated segment passes over the attached larvae.

For aerial applications where different-sized streams are to be treated in one operation, the dosages are estimated on a swath-acre basis. In the Alaska tests a single spray swath across the streams with a Piper Cub plane delivering 0.2 pound of DDT per acre, based on a swath width of 100 feet, completely eliminated the larvae for a half mile downstream. Similarly, with a C–47 plane covering an estimated swath of 800 feet, 0.1 pound of DDT per acre (½ pint of a 20-percent solution) gave complete control for 1½ miles in one test and for 2 to 2½ miles in five other tests. These dosages were equivalent to about 0.0005 pound of DDT per foot of stream width for the small plane and 0.002 pound for the large plane, much lower than the dosages recommended for hand application. These dosages should be increased for dense forest cover or deep, swift streams. For initial trials in aerial operations it is suggested that the control area be covered with parallel flights at intervals of ⅛ to ½ mile with the smaller plane and ½ to 1 mile with the larger one.

In a large-scale treatment of the Saskatchewan River in western Canada for the control of *Simulium arcticum* Malloch, a DDT solution applied by airplane at the rate of 0.13 p. p. m. of DDT for 36 minutes destroyed practically all larvae for about 100 miles downstream. A total of 615 pounds of DDT, or about ½ pound per foot, was applied during repeated runs across the river where the width was about 1,200 feet. The flow of water at this point was estimated at 35,220 cubic feet per second. Chemical analysis of the water 5 miles downstream showed that the section of treated water had lengthened considerably, with a consequent reduction in concentration of DDT. It is suggested that all streams containing black fly larvae be treated within at least 5 miles from the area to be protected.

At the dosages recommended no harmful effect on fish would be expected, as they were found to withstand much larger amounts. Some reduction of aquatic insects other then simuliids may occur but should not be serious except possibly for a short distance below the points of treatment.

TICKS

Ticks are vectors of Rocky Mountain spotted fever, Bullis fever, numerous other rickettsial diseases, tularemia, and Q fever, as well as pests of man and domestic animals in many areas. Tick control is usually aimed at the prevention of their development on animal hosts and often requires long campaigns. For the immediate protection of troops in the field the use of clothing impregnated with a repellent is the most feasible method now available (see pp. 75–80). Area control of both ticks and chiggers in and around campsites is sometimes desirable.

The commonest species of wood ticks in the Eastern United States are the American dog tick and the lone star tick. DDT, chlordane, dieldrin, and toxaphene have given satisfactory control of these species and presumably would be effective against others. Dosages of 1 to 2 pounds per acre in solutions or emulsions or 2 to 3 pounds in 10-percent dusts are recommended. Thorough application should be made to the litter on the ground and to low vegetation. Parathion gave good control of the lone star tick at ¼ to ½ pound per acre, but because of its high toxicity to humans it is not recommended for general use.

Only the adults of the American dog tick attack man, and they usually congregate on vegetation along the edges of roads and trails. A high degree of control has been accomplished by treating a strip 20 to 30 feet wide on each side of the road or trail. The larvae and nymphs as well as adults of the lone star tick will attach themselves to persons, and the three stages are found principally in brushy thickets that are commonly used by deer. Application of insecticides in some localities may be limited to such thickets. For either species a preliminary survey should be made to determine the location of the heaviest infestations. A white flannel cloth dragged over the grass and ground duff will show these places.

Ticks infesting living quarters and other buildings are usually brown dog ticks. They can be killed with DDT or chlordane. A spray containing 5 percent of DDT or 2 percent of chlordane should be applied to cracks, crevices, and behind objects where the ticks hide. A combination spray and dust treatment may be advantageous if the hiding places cannot be readily reached by the spray.

Both the American and the brown dog ticks are brought onto the premises by dogs. These ticks can be controlled with a wash containing 1 percent of DDT or 0.01 percent of lindane. A DDT wettable powder or a lindane emulsifiable concentrate should be used to prepare the wash. A 10-percent DDT dust may also be used, but it is less thorough and effective. Derris or cube washes or powders have long been in use for tick control on dogs. A suitable wash may be made by mixing 2 ounces of fine derris or cube powder and 1 ounce of neutral soap in 1 gallon of tepid water. The powder should contain at least 3 percent of rotenone.

CHIGGERS

The larvae of trombiculid mites, commonly called chiggers or redbugs, are important pests of troops in some parts of the United States

and elsewhere. They are also the vectors of scrub typhus, or tsutsugamushi disease, in the Oriental and Australasian regions.

Chiggers are commonly found on damp ground protected by vegetation or leaf mold, such as margins of lakes and streams, shady woods, high grass or weeds, and briar patches. They also are picked up at times on lawns, golf courses, and in parks. Decaying logs and branches are often heavily infested. Because of their small size chiggers are not easily seen except against a shiny black background. To locate infested areas a piece of black cardboard may be placed edgewise on the ground in places that appear favorable for the pests, or black oilcloth may be spread over stumps, logs, or dead twigs. After a few moments the chiggers may be seen moving rapidly over the surface and accumulating on the upper edge. They can also be detected on polished black shoes, and these are sometimes used for a rapid survey.

DDT is not very effective against chiggers, but dieldrin, chlordane, toxaphene, and BHC have all given good control when sprayed on infested ground at rates of 1 to 2 pounds per acre. Emulsion sprays gave the best results, but dusts were also effective in some tests. Dieldrin at 1 pound and toxaphene at 2 pounds per acre maintained a high degree of control for 1 to 2 months or more. The other materials were slightly less effective and less consistent.

The treatment of clothing as protection against chiggers is discussed on pages 75–80.

REPELLENTS

More than 10,000 chemicals were given screening tests as mosquito repellents at the Orlando laboratory. Many of them were synthesized especially for this purpose during the war by university groups under contracts with the Office of Scientific Research and Development. Smaller numbers were tested against other insects, usually after their repellency to mosquitoes had been demonstrated. In the laboratory tests several hundred of the liquid compounds, when applied to the skin, gave complete protection against the yellow-fever mosquito for 3 hours or more, and were placed in the most effective category (class 4). However, most of them were eliminated from further consideration because of skin irritation or sensitization, disagreeable odor, or staining properties. Others were not available in sufficient quantity for further testing. The remainder were subjected to extensive evaluation in laboratory and field tests under various conditions and against different species of mosquitoes.

REPELLENTS APPLIED TO THE SKIN

It was shown in these studies that a repellent may differ greatly in effectiveness against different species. Therefore an investigation was made of mixtures as a means of providing protection against a wider range of species. In this way the mixture known as 6–2–2 was developed and adopted as standard issue. It contained 6 parts of dimethyl phthalate and 2 parts each of 2-ethyl-1,3-hexanediol and Indalone. Indalone was included because of its effectiveness particularly against the biting stable fly, but as this species is seldom important as a pest of persons, it was later eliminated and other

compounds substituted. Propyl *N,N*-diethylsuccinamate and dimethyl carbate were particularly effective against the subarctic species of mosquitoes, and mixtures containing them were covered in one specification (No. 21). One of these mixtures is known as M–2020 and contains dimethyl phthalate, 2-ethyl-1,3-hexanediol, and dimethyl carbate. The other, M–2043, contains propyl *N,N*-diethylsuccinamate in place of dimethyl carbate. Until additional information is obtained on the effects of propyl *N,N*-diethylsuccinamate on women and children, this material alone or in combination with the other repellents named is not recommended for civilian use.

All these repellents have also shown a high degree of repellency to black flies and a lesser degree to culicoid sand flies.

In applying a liquid repellent one should shake about 12 drops into one hand, rub the hands together, and smear the repellent in a thin layer over the face, neck, ears, hands, and wrists. It must be uniformly distributed, as the insects will find places that are inadequately treated. Care should be taken to keep the liquid out of the eyes as it will cause temporary stinging.

The best repellents should give protection for several hours, but the time will depend on the amount applied, atmospheric humidity, body perspiration, rubbing of the treated areas, and the kind and number of insects and their determination to obtain blood. Perspiration particularly affects the protection time by removing the repellent. There is also an unexplained variation in effectiveness between individual users.

The incorporation of repellents in powder-base creams, particularly zinc oxide preparations, was found to increase the time of protection with the same amount of repellent. Work is under way to develop cosmetic-type lotions that will be more acceptable to the user than liquid repellents.

REPELLENTS APPLIED TO CLOTHING

Solid compounds as well as many of the liquids were given screening tests by applying them to articles of clothing and testing them against yellow-fever mosquitoes. When employed in this manner the duration of effectiveness of a repellent is measured in days compared with hours when applied to the skin. The best compounds selected in these tests and nearly all of the class 4 skin repellents were subjected to laboratory and field evaluation to determine the ones most promising for practical use. They were observed for odor, staining, and skin irritation, and from those proved to be safe toxicologically selections were finally made on the basis of duration of effectiveness when the impregnated garments were worn in the field. Nearly all the good skin repellents were effective when applied to cloth, but the best ones on the skin were usually not the most durable on cloth.

Most of the materials placed in class 3 (effective 6 to 10 days) or 4 (effective more than 10 days) as mosquito repellents were also screened as clothing treatments for effectiveness against fleas and ticks. The flea tests were conducted against the cat flea and the Oriental rat flea. For the tick tests, the lone star tick was used in the laboratory, and field tests were run in areas infested with either this tick or the American dog tick.

Chiggers were included among the pests against which a clothing treatment was needed. A material was desired that would cause rapid knockdown and also withstand wetting and laundering of the treated clothing. The good mosquito skin repellents, especially dimethyl phthalate and 2-ethyl-1,3-hexanediol, were very effective when applied to clothing but did not withstand water. Since chiggers that crawled onto freshly treated clothing were quickly immobilized, the materials acted as toxicants rather than repellents. Dibutyl phthalate was slightly more resistant to water but was not entirely dependable even after one laundering. Benzyl benzoate was found to give complete protection after two launderings and a high degree of protection after three launderings. A mixture of equal parts of benzyl benzoate and dibutyl phthalate was about as effective as benzyl benzoate alone. Both repellents were adopted during World War II for standard issue (No. 19).

In subsequent work several compounds were found that were effective after 5 to 10 hot-water launderings. The most promising were diphenyl carbonate, *p*-tolyl benzoate, and benzil. They were also effective when incorporated in powders and dusted on the garments. Toxicological studies by the Army Environmental Health Laboratory indicated that the first two compounds cause skin sensitization; so they were not considered safe for use. Although benzil was not objectionable from this standpoint, it did cause skin irritation to some individuals wearing garments impregnated with it in combination with other repellents.

Of the materials that were considered safe and practicable for use on clothing worn by military personnel, the following gave the best protection against the different pests:

- Mosquitoes:
  - 2-Butyl-2-ethyl-1,3-propanediol.
  - *N*-Butyl-4-cyclohexene-1,2-dicarboximide.
  - Hendecenoic acid (undecenoic or undecylenic acid).
  - Propyl *N,N*-diethylsuccinamate.
- Fleas:
  - Hendecenoic acid.
  - Benzyl benzoate.
  - *N*-Butylacetanilide.
- Ticks:
  - *N*-Butylacetanilide.
  - *N*-Propylacetanilide.
  - Hexyl mandelate.
  - Indalone.
- Chiggers:
  - Benzyl benzoate.
  - Dibutyl phthalate.
  - Dimethyl phthalate (and other mosquito repellents).

Repellent Mixtures for Clothing Treatment

A great deal of attention has been given to the development of an all-purpose mixture of repellents that would provide in a single treatment protection against the most important species of mosquitoes, fleas, ticks, and chiggers. Various combinations of the most effective individual materials were tried, and the one that appeared to give the best all-round results, M–1960, was recommended to the Department of Defense and used during the Korean war. This mixture contains *N*-butylacetanilide, benzyl benzoate, and 2-butyl-2-ethyl-1,3-pro-

panediol, with Tween 80 as an emulsifier. The M–1960 formula has not been approved for use by civilians because of insufficient information on the effects of the materials on women and children.

Methods of Application to Clothing

For temporary or occasional use the individual repellents, including chigger toxicants, may be applied to the clothing as needed either by hand smearing or with a small spray gun (fig. 30). For mosquitoes

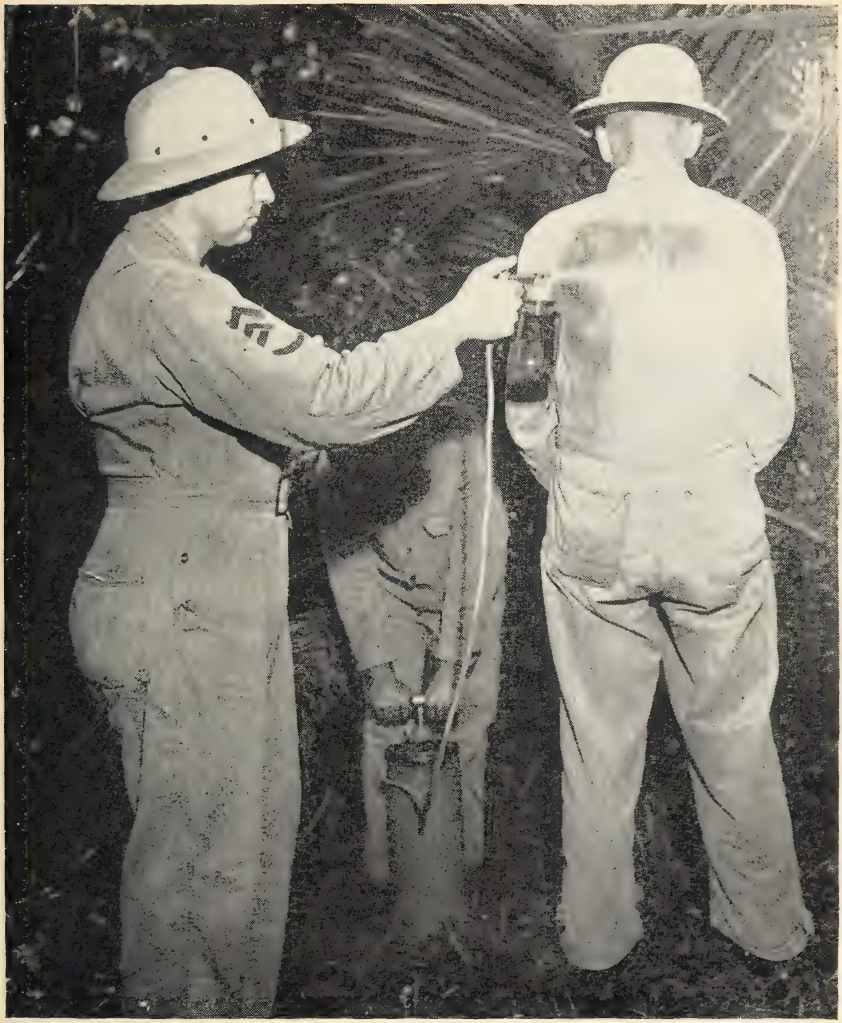

FIGURE 30.—Applying mosquito repellent to clothing with a paint spray gun.

the applications are made to portions of the garments where the most bites occur, as across the shoulders and around the knees. For chiggers the barrier method is employed, whereby the material is applied in a narrow band around all the garment openings, especially the cuffs,

waistband, and fly of the trousers, the socks above the shoe tops, and the eyelets of the shoes (fig. 31). For fleas or ticks the trouser legs should be treated as far as the knees or even to the waist.

For protection of troops during prolonged field exposure, the impregnation of entire uniforms is considered the most practical method of utilizing repellents. Either emulsions or solutions in such volatile solvents as acetone, xylene, or dry-cleaning compounds may be used. Solutions and emulsions gave about equal results in tests with tick repellents. Generally an emulsion is recommended, because water for dilution can be obtained at the time and site of treatment, so that transportation of only the concentrate is required. Occasionally mass impregnation may be done most conveniently with solutions in dry-cleaning equipment.

The individual repellents are applied at the rate of about 2 grams per square foot of cloth, which is equivalent to about 75 ml., or 2½ fluid ounces, to a two-piece uniform. A pair of socks should be included with the uniform. The minimum volume of liquid required to saturate such an outfit is about 3½ pints, and the proper amount of repellent is contained in this quantity of a 5-percent solution or emulsion.

FIGURE 31.—Applying chigger repellent to trouser cuff.

One person pours the liquid over the uniform in a pan or large bucket while a second person turns and squeezes the cloth to insure even and complete wetting. Where a number of suits are to be treated, it is recommended that a stock emulsion be prepared in a barrel or drum and the required amount (3¼ to 3½ pints) be dipped out for individual suits. The stock should be stirred occasionally to maintain the emulsion. It is not advisable to dip the uniforms one after another in the stock emulsion, as this tends to break the emulsion or to change the concentration. After the clothing has been treated, it should be laid out, if possible, on a clean surface to dry or hung on a line. After drying, if the clothing is not to be worn immediately, it should be folded compactly and stored indoors.

If an emulsifier or an emulsifiable concentrate is not available, Quartermaster-issue laundry soap can be used. The soap should be shaved into cold water, heated to boiling, and the required amount of cold water added to form a 2-percent solution. In a separate dish the repellent is then stirred vigorously into an equal quantity of this soap solution with a wire egg whip (which is a standard item of army kitchen equipment) or other device. This concentrate is diluted with additional soap solution to make the finished emulsion containing 5 percent of repellent. One 14-ounce bar of laundry soap, 5¼ gallons of water, and 34 fluid ounces of repellent provide about the proper quantity of emulsion for wetting 13 uniforms.

One gallon of the all-purpose mixture M–1960 (pp. 76–77) is sufficient to impregnate 28 full uniforms by hand treatment, or about 13 in a Quartermaster-issue portable laundry. For hand treatment the concentrate is mixed at the rate of 1 part to 11 parts of water. Approximately 135 ml. of concentrate, or 1,600 ml. of emulsion, per uniform gives the desired dosage of a little more than 3 grams of the active ingredients per square foot of cloth. The uniforms are treated individually as previously described.

Cotton or wool clothing can also be impregnated satisfactorily on a large scale in Quartermaster semimobile laundries. The recommended procedures for impregnating cotton clothing with M–1960 are as follows:

With 60 pounds of clothing in the washer, follow the usual washing procedure through the last rinse. If it is necessary to save time by altering the procedure, eliminate the third rinse and put sour in the second rinse. Drain the last rinse water from the washer. With the outlet valve to the drain open, roll the washer with the clothing in it for 2 minutes to remove excess water. Close the outlet valve, and with the washer rolling add an emulsion composed of 4 gallons of water and 1½ gallons of M–1960. The emulsion should be mixed in a container before being placed in the washer. Roll for 3 minutes. Then drain the emulsion from the washer. Catch the first 4½ gallons of emulsion that runs from the washer in one container and the remainder in a second container. If the volume of emulsion in the latter is 3 gallons or less, the treatment was probably satisfactory. If so, 1 gallon of M–1960 is added to the 4½ gallons of emulsion first recovered and used for the next treatment. Discard the emulsion in the second container.

A more accurate but more time-consuming method is as follows:

Proceed as in the first method, but collect the first 5 gallons of used emulsion that runs from the washer in the first container for use in the next treatment. Determine the percentage of M–1960 present in the used emulsion, as follows:

Collect a 100-ml. sample of the M–1960 in a 100-ml. glass-stoppered graduate and add approximately 28 grams (23–25 cc. measured in a 25-ml. graduated cylinder or 3 level tablespoonfuls) of sodium chloride (U. S. P.—common table salt usually contains calcium silicate, which interferes with an exact reading), insert the stopper, and shake vigorously to dissolve the salt. Set aside until the oil and aqueous phases separate (3–5 minutes usually). When the separation is complete, carefully invert the cylinder with the stopper tightly in position and read the volume of the oil phase. This reading is a direct percentage (v/v) of the M–1960.

After the concentration of the recovered emulsion has been determined, part or all of it may be combined with an additional quantity of M–1960 to make the next treatment. The amounts of recovered emulsion and M–1960 to be used are as follows:

If the percent concentration of the recovered emulsion is—	*Prepare the next emulsion by using the following quantities of—*			
	Recovered emulsion		*M–1960*	
	Gallons	*Pints*	*Gallons*	*Pints*
4–5	4	1	1	3
6–7	4	2	1	2
8–9	4	3	1	1
10–13	4	4	1	------
14–15	4	5	------	7
16–17	4	6	------	6
18–19	4	7	------	5
20–21	5	------	------	4

After the same emulsion has been used for 6 to 10 treatments, it will usually become dirty, and the entire emulsion should then be discarded.

For woolen clothing follow the usual washing procedure through the last rinse. Drain the last rinse water from the washer. With the outlet valve to the drain open, roll the washer with the clothing in it for 2 minutes to remove some of the excess water. Close the outlet valve, and with the washer rolling add an emulsion composed of 6¾ gallons of water and ¾ gallon of M–1960. Roll for 3 minutes. Spin and dry the clothing in the usual manner.

Do not save the emulsion drained from the washer. Because of selective absorption of M–1960 by wool, the concentration of repellent in the drained emulsion is very low.

Clothing treated with the repellents discussed herein may be expected to give protection for at least a week of continuous wear unless the repellent is washed out by rain or wading. The clothing should be reimpregnated after each laundering.

PROTECTION OF ANIMALS FROM INSECT ATTACK

A special insecticide formulation has been developed for protecting pack and other animals from attack by insects. It is an emulsifiable concentrate containing, by weight, 5 percent of pyrethrins, 25 percent of piperonyl butoxide, and 10 percent of emulsifier in deodorized kerosene.

Pack animals should be sprayed or sponged with an emulsion containing 1 part of the concentrate to 50 parts of water. For treating one animal to prevent attack by flies, add ¾ ounce to 1 quart of water and mix by shaking. About 2 quarts is required to wet an animal sufficiently to control lice or ticks.

This treatment will protect animals from attack by stable flies, horse flies, and deer flies for 2 to 3 days. If the animal is working and sweating profusely, daily treatments may be required. For tick protection weekly treatments may be sufficient. For louse control two treatments 2 weeks apart are recommended.

TOXICOLOGY OF INSECTICIDES AND REPELLENTS

An important phase in the development of chemicals for controlling insects is a study of their toxicity to appraise the hazard to man, domestic animals, wildlife, and beneficial organisms of all kinds. The nature of the hazard obviously depends on the manner of use and the length of time and degree of exposure to the chemical. Many agencies and individuals have contributed to our knowledge on the toxicity of insecticides and certain repellents. The information obtained has made it possible to select safe materials. Many effective insecticides and repellents are not recommended for specific purposes, because they are too hazardous or insufficient information is available to determine if and how they may be used safely.

During World War II the Division of Pharmacology of the Food and Drug Administration and the Industrial Hygiene Laboratories of the National Institutes of Health investigated the toxicity of promising insecticides and repellents that were being developed for the military services at the Orlando and Beltsville laboratories.

Since World War II many new insecticides and repellents have been found useful in the general field of applied entomology. Information on their toxicity to animals has been obtained by the U. S. Food and Drug Administration, the Public Health Service, the Army Environmental Health Laboratory, the Department of Agriculture, industrial pharmacological laboratories, and State experiment stations.

Since many insecticides are used for controlling insects attacking man as well as agricultural pests, much research has been designed to appraise their hazards to man and animals when used for controlling plant and livestock pests. The toxicity studies conducted by the Army Environmental Health Laboratory, however, were designed specifically to appraise the toxicity of repellents and insecticides for use on man. The research was closely coordinated with the biological studies conducted at the Orlando laboratory. The Public Health Service has investigated the toxicity of some of the insecticides employed by State and Federal health agencies in connection with the control of communicable diseases transmitted by insects.

The Fish and Wildlife Service, the Public Health Service, the Tennessee Valley Authority, and the Department of Agriculture have conducted investigations to determine the effects of insecticides on wildlife, fish and other aquatic life, and on beneficial insects.

NATURE OF HAZARDS

Some of the materials described in this circular must be applied directly to the body. Other materials, not intended for direct application to the body, must be handled in highly concentrated form and are dangerous if accidentally spilled on the body. To destroy certain disease vectors or pests, the treatment of living quarters is necessary. The use of insecticides and repellents for controlling insects of medical importance, therefore, results in unavoidable exposure of man to chemicals used in this manner.

Other treatments are made over extensive areas where man or animals might be exposed to the chemicals by contact, inhalation, or ingestion. In such varied uses consideration must be given not only to acute but to chronic poisoning.

The most important factors to be considered in appraising the hazard of a given chemical treatment are (1) its acute toxicity, (2) accumulative or chronic toxicity, (3) composition of the formulated material, (4) concentration of toxicants handled in mixing or applying the treatment, (5) amount of a given chemical that must be applied to achieve insect control, (6) frequency of application, (7) conditions under which the chemical is applied and degree of exposure to the residues, and (8) physical and chemical properties of the material.

The inherent acute toxicity of a material is obviously the most important criterion for estimating its hazard in handling, because most of the items used by the military are, for logistical reasons, packaged in highly concentrated form. If safe handling procedures are developed and practiced, the relative hazard of the material is then governed largely by the other factors.

Sometimes the more toxic chemicals are used in such low concentrations and applied in such small amounts that the risk involved in their use is less than that of other less toxic chemicals that must be applied in larger amounts.

Those responsible for recommending or supervising the use of insecticides and repellents should make every effort to obtain information on their toxicity and to encourage their proper and safe use.

GENERAL PRECAUTIONS

It is a sound safety measure to regard all insecticides as hazardous to man and animals. The fact that they kill insects suggests that they are likely to be harmful to man and animals under excessive exposure. Kerosene, xylene, methylated naphthalenes, and other solvents used in preparing many insecticide formulations are themselves sufficiently toxic to cause illness or even death if there is careless exposure to them. Improper use of insecticides may also be harmful to animals, fish, and other beneficial organisms. Insecticides or solvents may injure plants if improperly used.

The following general precautions should be observed in the use of insecticides:

1. Handle all concentrates with care and avoid spillage on body or clothing. Wash off immediately any that is accidentally spilled on the body. If spilled on the clothing, change immediately.
2. Avoid unnecessary and prolonged exposure to sprays, mists, or dusts during application. Wear a respirator and suitable clothing to reduce inhalation and contact.
3. Avoid contaminating foods, drinking water, and food and water utensils.
4. Store insecticides and equipment used for mixing and applying them where they cannot be reached by children or animals. The containers should be distinctly labeled.
5. Do not apply oil-base sprays to man or animals. Solvents commonly used to prepare insecticides may alone cause severe harm.
6. Do not apply oil-base sprays to vegetation in quantities sufficient to wet the plants.
7. Exercise care in discarding unused insecticide materials. Drainage into watering ponds or streams may poison animals, including livestock, and fish.
8. Do not apply flammable insecticides near flames. When applying oil-base sprays inside of buildings, extinguish all fires and provide as much ventilation as possible. Thoroughly air the buildings after residual spraying.
9. Remove fish, birds, and pets from houses while applying residual sprays. Space sprays may also injure fish and birds. Either remove them from the rooms being treated or cover them.
10. Do not apply more than the amount of insecticide recommended for each specific use. There is particular danger in harming animals, fish, and wildlife if excessive amounts are applied for controlling mosquitoes, ticks, and other arthropods.
11. In applying even small amounts of insecticides, such as oil solutions on open bodies of water for mosquito control, keep in mind that wind and wave action may cause shifting of the film on the windward side. This may concentrate the insecticide in amounts that will destroy fish or other aquatic life.
12. Use sturdy equipment and maintain it in proper condition to avoid leakage and contamination of skin and clothing.
13. Check directions for mixing and applying insecticides. If in doubt about the use of any material, consult a specialist.

DDT

DDT is being used for more purposes in medical entomology than any other insecticide. It was the first synthetic organic compound employed extensively and has been the most thoroughly investigated toxicologically.

The median lethal oral dose of DDT to laboratory animals (such as rats, rabbits, and guinea pigs) is about 250 mg. per kilogram of body weight.[4] When applied to the skin in dry form it shows no

[4] Unless otherwise stated, the information on toxicity to laboratory animals was obtained from a series of articles by Arnold J. Lehman, entitled "Chemicals in Foods: A Report to the Association of Food and Drug Officials on Current Developments, Part II. Pesticides." Assoc. Food and Drug Off. U. S. 15: 122–133 (1951); 16: 3–9, 47–53 (1952).

gross toxic effect. In solution laboratory animals can tolerate single dermal exposures of about 3 grams per kilogram of body weight. Calves less than 1 month old, which are generally the most susceptible livestock, can tolerate emulsion or wettable-powder sprays containing 8 percent or more of DDT.[5] Treatment of cattle with a 2-percent DDT spray 10 times at 2-week intervals caused no clinical symptoms of poisoning.

On the basis of acute-toxicity data and the wide use experience in the direct treatment of persons, as for louse control, and in residual spraying in homes, DDT as recommended for controlling insects affecting man creates no undue acute hazard. However, the danger to guard against is the chronic hazard that may result from its improper and careless use, particularly in food contamination. The Food and Drug Administration has reported that 5 p. p. m. of DDT in the diet of laboratory animals will in time cause some liver damage. The insecticide is readily stored in fatty tissues when consumed or absorbed through the skin. It is slowly eliminated from the body. DDT is also excreted in the milk of animals when applied to them or when consumed in the diet. The time required for DDT to be eliminated from the animal system depends on the amount stored, but it may be several months to a year. It should therefore be used in such a manner as to avoid food contamination.

Extensive investigations have shown that, if improperly used or if applied in excessive amount, DDT may cause serious harm to fish, birds, mammals, and other beneficial organisms.

Special Precautions in Using DDT

Do not use DDT emulsions in waters containing fish. The insecticide is much more toxic in this form than in dusts, oil solutions, or suspensions.

DDT in oil solutions at the rate of 0.3 pound per acre may destroy fish and other aquatic life. Do not exceed this rate of application in bodies of water containing fish.

Do not apply in excess of 2 to 4 pounds of DDT per acre in residual sprays to vegetation or the ground, since higher dosages may prove harmful to birds, mammals, or other beneficial life.

Do not use inside dairy barns or milk rooms.

PYRETHRUM AND ALLETHRIN

Pyrethrum and allethrin, and the synergists piperonyl butoxide, sulfoxide, sesame oil, and propyl isome used with these insecticides, are all low in toxicity to animals from the standpoint of both acute and chronic exposure either orally or dermally.

When used as recommended for insect control these insecticides create no undue hazards. However, the general precautions on pages 82–83 should be followed.

METHOXYCHLOR

Methoxychlor is related to DDT chemically but is much less toxic to animals both acutely and chronically. It is perhaps the least toxic

[5] Information on the toxicity of the various insecticides to livestock was obtained from "Toxicity to Livestock," by Radeleff, R. D., Bushland, R. C., and Claborn, H. V., in Insects, Yearbook of Agriculture 1952, pp. 276–283, and from unpublished data obtained at the Kerrville, Tex., laboratory.

of the chlorinated hydrocarbon insecticides. The median lethal oral dose for laboratory animals is about 6 grams per kilogram of body weight. Unlike DDT, it is not readily stored in animal fat or excreted in milk when applied to or consumed by animals. Because of its low toxicity it is considered safe as normally used for insect control, including applications inside dairy barns and milk rooms for fly control and on dairy pastures that may require treatment for mosquito control.

The toxicity of methoxychlor to fish and other aquatic life is not well known. For mosquito control it should be used with the same precautions outlined for DDT (see p. 84).

TDE

TDE is also related chemically to DDT. Its acute oral toxicity to animals is lower than that of DDT but higher than that of methoxychlor. The median lethal oral dose to laboratory animals is about 3.4 grams per kilogram of body weight. It is low in toxicity to livestock; concentrations up to 8 percent in emulsion sprays caused no harm to calves.

The chronic toxicity is lower than that of DDT but higher than that of methoxychlor. TDE is stored in animal fat in about the same degree as DDT when taken orally or absorbed through the skin. It is also excreted in milk to about the same extent as DDT.

Although generally less toxic to animals than DDT, TDE should be used with the same precautions (see p. 84).

BHC (BENZENE HEXACHLORIDE)

The several isomers of BHC vary in their toxicity to animals as well as to insects. The gamma isomer is the most toxic to insects. Most technical BHC contains about 12 percent of this isomer, but some preparations are available in which the gamma concentration ranges almost to that of lindane (99 percent).

The acute oral toxicity of BHC to rats is lower than that of DDT. Some of the isomers are readily stored in the fat of animals when consumed in the diet or absorbed through the skin. The residues stored in fat are not quickly eliminated.

BHC is volatile, and the vapors may prove harmful on excessive exposure.

The musty odor of BHC is a serious objection to its use inside living establishments. It may also lead to tainting of foods if they are accidentally contaminated or if the material is applied to soils in which certain crops are grown.

BHC is regarded as one of the least toxic of the chlorinated hydrocarbon insecticides to fish.

Special Precautions in Using BHC

Do not apply to edible food crops or to soils where vegetables and other crops are grown.

Do not use inside homes.

Do not apply inside dairy barns or milk rooms.

Do not use on man.

Avoid excessive exposure to mists and sprays, especially oil solutions.

LINDANE

Lindane is the name given to the practically pure gamma isomer (99 percent) of benzene hexachloride. For the control of some insects it may be used in smaller amounts than DDT, chlordane, and some of the other chlorinated hydrocarbons. It does not have the objectionable musty odor of technical BHC.

Lindane is less toxic chronically than BHC. However, its acute toxicity to man and animals, either orally or dermally, is higher than that of technical BHC or DDT. The median lethal oral dose for laboratory animals averages about 125 mg. per kilogram of body weight. Dermal applications are many times as toxic as those of DDT. Emulsion or wettable-powder sprays containing as little as 0.05 percent of lindane may cause toxic symptoms in calves. Older cattle may tolerate much higher concentrations. The physical condition of the animal affects its susceptibility to lindane. For example, sheep in good condition may tolerate sprays containing 0.25 percent of lindane, whereas extremely emaciated sheep may become poisoned by concentrations as low as 0.03 percent.

The Food and Drug Administration regards the chronic oral toxicity of lindane to be about one-fourth that of DDT. Because it is usually employed in low concentrations, food contamination from sprays and dusts is less likely than from those containing DDT. However, lindane vapors may be formed and recondensed on objects and food, and thus offset this advantage.

Lindane appears in milk of dairy cows that have been sprayed with or have consumed the chemical in the diet. However, it does not readily accumulate in the system and is eliminated from the body in a much shorter time than is DDT.

The vapors of lindane are highly effective against insects. This property is utilized to control flies, mosquitoes, and other pests by volatizing lindane inside of buildings. However, the vapors on long exposure or in high concentrations may also be toxic to people.

Special Precautions in Using Lindane

Avoid excessive dermal exposure, especially to oil solutions.

In using lindane vaporizers in homes, do not expose people continuously to the vapors for long periods.

Restrict residual applications to spot treatments in living quarters for controlling roaches, ants, and flies. In some parts of the world the treatment of living quarters with lindane is required for controlling malaria or other insect-borne diseases. However, it should be applied by experienced operators under the supervision of responsible agencies.

CHLORDANE

The chronic toxicity of chlordane appears to be higher than that of DDT although available data are not in agreement on this point. The differences may be due to variations in the composition of the manufactured product.

The acute median lethal oral dose for laboratory animals is about 457 mg. per kilogram of body weight, which is higher than that of DDT. When fed in the diet of laboratory animals 2.5 p. p. m. is

reported to damage tissue. A single application of 1-percent spray has caused toxic effects in calves. On cattle 2-percent sprays produced toxic effects after 2 or 3 treatments 2 weeks apart. DDT and toxaphene applied at the same time, concentration, and interval caused no observable toxic effects after 10 treatments.

Chlordane is not stored in fat of beef cattle so readily as is DDT, and it is eliminated more quickly.

Chlordane is volatile, and the vapors may create a hazard when large amounts are applied in buildings. The toxic effects of such vapors to man and animals have not been well established.

Special Precautions in Using Chlordane

Do not apply on man.

Do not use for residual treatment of large areas of walls and ceilings in homes and industrial establishments. Limit its use to spot treatments in places where such pests as cockroaches, ants, and silverfish hide and run.

Do not apply in dairy barns or milk rooms.

To avoid possible damage to fish and wildlife, exercise the same precautions listed for DDT (see p. 84).

TOXAPHENE

The acute oral toxicity of toxaphene is much higher than that of DDT, chlordane, or lindane. The median lethal oral dose for laboratory animals is about 69 mg. per kilogram of body weight. The chronic oral toxicity is lower than that of DDT or chlordane.

When applied to calves toxaphene is much more toxic acutely than DDT, but less so than lindane. Calves are poisoned occasionally when treated with 1-percent sprays, which represents about the same acute dermal toxicity as for chlordane. However, in contrast to chlordane repeated treatment of calves every 2 weeks or at even shorter intervals caused no accumulative toxic effects. When consumed orally toxaphene is not readily stored in body fat and is not readily excreted in milk of dairy cattle. When storage does occur at rather high levels of intake, the residues disappear from the body much more quickly than those of DDT.

Toxaphene is highly toxic to fish.

Special Precautions in Using Toxaphene

Do not apply on man.

Do not use inside homes.

Do not use for controlling mosquito larvae if fish are present.

For chigger or tick control near streams or ponds apply carefully to avoid accidental contamination of the water.

DIELDRIN

The major limiting factor in the use of dieldrin is its high acute and chronic toxicity to man and animals. Its acute oral toxicity to laboratory animals was found to be about 87 mg. per kilogram of body weight on the basis of the median lethal dose.

On the same basis the acute dermal toxicity of dieldrin in oil averages less than 150 mg. per kilogram of body weight. On repeated

application this dose averages less than 5 mg. per kilogram of body weight.

From the standpoint of subacute or chronic toxicity, 25 p. p. m. in the diet damages tissue. A feeding level of 50 p. p. m. causes gross toxic effects. No information on the effects of lower feeding levels is available.

The U. S. Public Health Service has investigated the toxicity of dieldrin when used in sprays. With proper precautions a concentration of 0.625 percent is regarded as safe. Sprays containing 0.25 percent of dieldrin proved acutely toxic to calves. Single treatments with a 0.1-percent concentration did not cause gross toxic symptoms. Older cattle tolerated single exposures at much higher concentrations, as is true for other chlorinated hydrocarbon insecticides. Repeated treatments with 0.5-percent sprays caused accumulative toxic effects in cattle.

Dieldrin is readily stored in fat and excreted in milk of cattle when it is consumed in the diet or absorbed through the skin. Like DDT, its residues are slowly eliminated.

Generally dieldrin is considered more toxic to animals than the other chlorinated hydrocarbon insecticides previously discussed. However, it is also much more toxic to insects. The smaller amounts required for insect control may offset the greater toxicity to animals.

Dieldrin should not be used for insect control except by trained personnel under responsible supervision.

Special Precautions in Using Dieldrin

Do not apply on man.

Do not use inside homes except for spot treatments at a concentration of 0.5 percent as a spray or 1 percent as a dust.

Do not contaminate ponds or streams.

Do not apply or allow to drift where livestock may feed.

Avoid contact with skin, eyes, and clothing.

Do not inhale vapors.

Consult a physician if contact or ingestion has occurred.

ALDRIN

Insofar as is known, aldrin is similar to dieldrin in mammalian toxicity and storage in fat. Like dieldrin it should also be used only by trained personnel under responsible supervision and with the same precautions as outlined for dieldrin.

HEPTACHLOR

Available data on the mammalian toxicity of heptachlor are limited, but the oral toxicity appears to be similar to that of aldrin and dieldrin. Little information is available regarding its chronic toxicity, storage in fat of animals, and excretion in milk.

Heptachlor should be used only by trained personnel under responsible supervision and with the same precautions as outlined for dieldrin.

PHOSPHORUS INSECTICIDES

Parathion

Owing to its high toxicity to mammals, the use of parathion for controlling insects affecting man is not advocated.

The acute median lethal oral dose of parathion for laboratory animals is about 3 mg. per kilogram of body weight, which is much lower than that of any of the chlorinated hydrocarbon insecticides. When it is applied to the skin, the acute median lethal dose is about 40 to 50 mg. per kilogram of body weight. Calves are poisoned when sprayed with a concentration as low as 0.025 percent.

EPN

EPN, like parathion, is highly toxic to mammals.

The acute median lethal oral dose for laboratory animals is about 14 mg. per kilogram of body weight, which represents about one-fourth the oral toxicity of parathion. The acute dermal toxicity is about the same as that of parathion. Although it is highly toxic to calves, these animals appear to be less susceptible to EPN sprays than parathion, the concentration causing death being about 2 to 4 times higher.

TEPP

TEPP is of little interest in medical entomology because of its high toxicity to animals and its short residual effectiveness, but it is used in baits for fly control.

The acute median lethal dose for laboratory animals is about 1.2 mg. per kilogram of body weight when given orally and about 5 mg. per kilogram when applied to the skin.

Malathion

Malathion is much less toxic to man and animals than the other phosphorus insecticides. Its acute oral toxicity to laboratory animals is less than that of DDT. The chronic oral toxic effects are also low.

The dermal toxicity to calves is about the same or slightly higher than that of toxaphene and chlordane. Sprays containing 1 percent caused fatalities. Concentrations of 0.5 and 0.25 percent produced no gross symptoms of toxicity.

Diazinon, Bayer L 13/59, and Chlorthion

Such toxicity data as are available at present indicate that Diazinon is about as toxic to warm-blooded animals as TEPP; Bayer L 13/59 and Chlorthion are much less toxic, perhaps even less so than malathion.

Special Precautions in Using Phosphorus Insecticides

The phosphorus insecticides previously discussed, as well as Systox (active ingredient demeton), schradan, methyl parathion, para-oxon, HETP, and similar insecticidal materials in common agricultural usage, are all cholinesterase inhibitors, and sublethal exposure to any one of them may increase the toxic effects of any other. Avoid continued exposure to any phosphorus insecticide.

In preparing phosphorus baits the chief hazard is in handling the concentrates to make the solutions or in mixing with the sugar in the dry baits. Take extreme care to avoid spilling the concentrates on the person or contaminating foods and utensils. There is much less hazard in handling the formulated baits because of the low concentration of toxicant, but the general precautions given on pages 82–83 should be followed.

REPELLENTS

Since repellents come into direct contact with the skin, the toxicity problem is especially important. Every repellent recommended for use by military personnel has been investigated by toxicologists to estimate its systemic toxic, irritant, and sensitizing effects on man. Clearance for use on military personnel does not constitute clearance for general use by civilians because of possibly greater susceptibility of women and children to the materials. However, the following repellents are considered satisfactory for civilian use: Dimethyl phthalate, 2-ethyl-1,3-hexanediol, Indalone, dimethyl carbate, and benzyl benzoate. The M–1960 formula for treatment of clothing and several skin repellent preparations have been cleared for use by military personnel but not for civilians.

No precise information on the toxicity of different repellents is presented in this circular. Toxicity data on which clearance for use has been based are available from the Food and Drug Administration and the Army Environmental Health Laboratory.

It is generally recognized that almost any substance may cause allergic reactions in some individuals. Apparently the incidence of such reactions has not been high since no harmful reactions have been reported in connection with the use of those repellents considered satisfactory for civilian use.

The repellents should not be considered innocuous. They may be harmful if allowed to get into the eyes or if ingested. They may also cause slight smarting of the skin, especially when perspiring. They damage paints, plastics, and most synthetic fabrics.

Special Precautions in Using Repellents

Do not allow to get into the eyes.

Store where small children cannot reach them.

Do not allow to come in contact with painted or varnished surfaces or plastics.

Do not apply on synthetic cloth, such as rayon.

If clothing is treated with a repellent, it is advisable to wear untreated undergarments. Direct contact of treated clothing may cause smarting of the tender parts of the body.

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